AD-A061 758 BOEING COMMERCIAL AIRPLANE CO SEATTLE WASH F/G 13/8
ANODIZE OPTIMIZATION AND ADHESIVE EVALUATIONS FOR REPAIR APPLIC--ETC(U)
JUL 78 M C LOCKE, R E HORTON, J E MCCARTY F33615-73-C-5171
UNCLASSIFIED AFML-TR-78-104 NL

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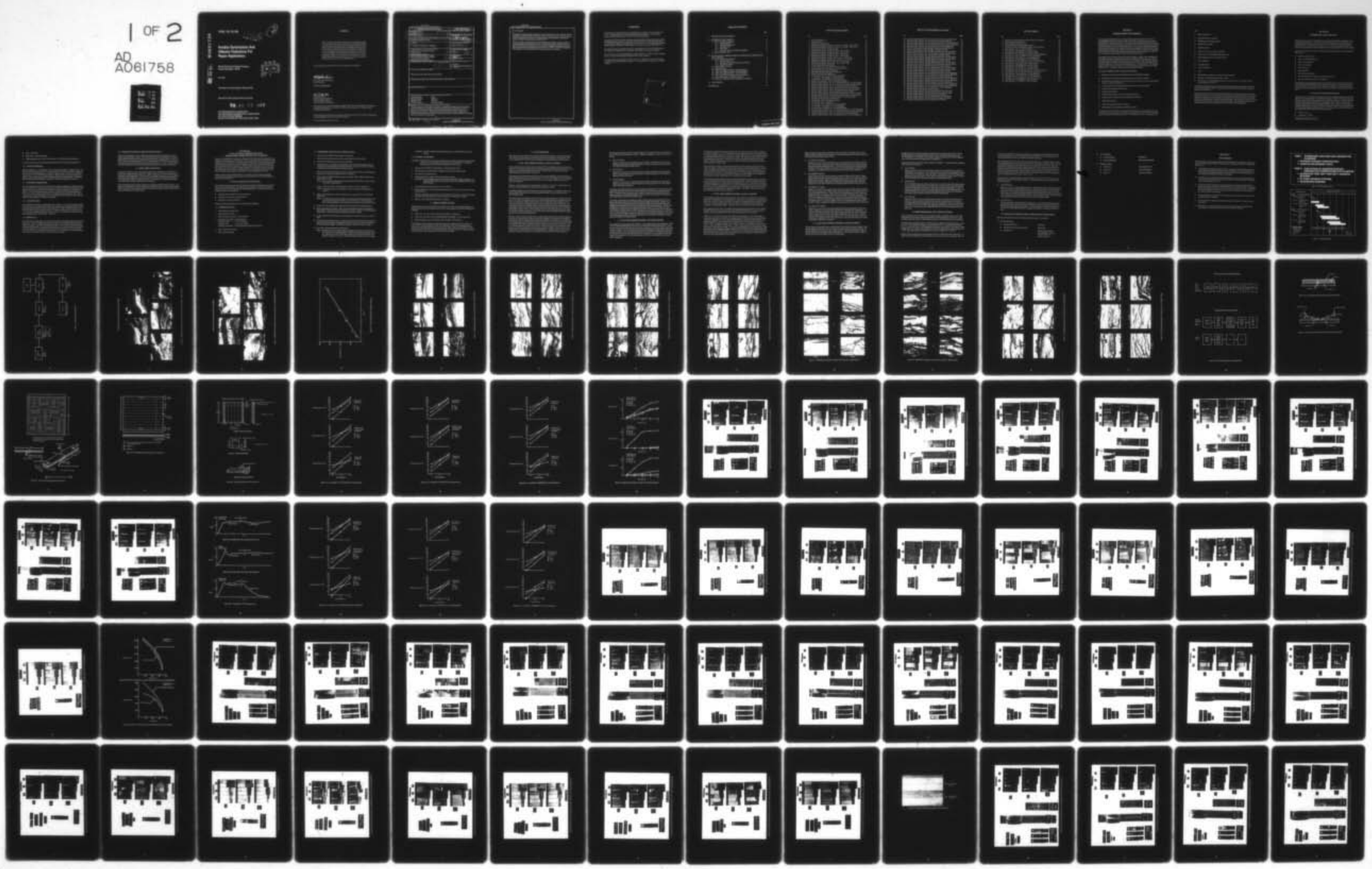

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LEVEL II

Anodize Optimization And Adhesive Evaluations For Repair Applications

Boeing Commercial Airplane Company
Seattle, Washington 98124

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DEC 4 1978
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July 1978

Final Report for Period December 1976–July 1978

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AIR FORCE MATERIALS LABORATORY
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WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICES

This technical report has been reviewed and is approved for publication.

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FOR THE COMMANDER

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This report has been reviewed by the Information Office (IO) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

AIR FORCE/56780/16 November 1978 — 400

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFML-TR-78-104	2. GOVT ACCESSION NO.
	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): ANODIZE OPTIMIZATION AND ADHESIVE EVALUATIONS FOR REPAIR APPLICATIONS	5. TYPE OF REPORT & PERIOD COVERED: Final Report, 1 Dec[redacted]76-30 [redacted]78
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): M. C. Locke, R. E. Horton J. E. McCarty	8. CONTRACT OR GRANT NUMBER(s): F33615-73-C-5171
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Boeing Commercial Airplane Company, P. O. Box 3707, Seattle, Washington 98124	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 7381-06-77
11. CONTROLLING OFFICE NAME AND ADDRESS: Air Force Materials Laboratory (MXE), Air Force Systems Command, Wright-Patterson AFB, Ohio 45433	12. REPORT DATE: July[redacted]978
	13. NUMBER OF PAGES: 114
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 123p	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

62102F

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Adhesive Bonding	Repair
Surface Preparation	Wedge Test
Phosphoric Acid	FPL Etch
Non-Tank Anodize	Stressed Durability

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report covers a two-task follow-on program to investigate phosphoric acid non-tank anodize process optimization and evaluation of adhesive/surface preparation combinations. Work completed in Task I included investigating non-tank anodizing process variables of voltage, time, temperature, and rinse delay. Other parameters studied included the effect of anodizing over titanium and aluminum fasteners, battery anodizing, anodizing mode, and identification of common errors occurring in non-tank anodizing.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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Following the anodizing variables investigation, bond verification tests were conducted to assess bondability of representative RT, 250°F, and 350°F cure adhesive systems. This work served as a basis for selecting the phosphoric acid non-tank anodize process parameter/conditions for Task II. The Task I work is reported in AFML-TR-78-7.

Task II was aimed at developing a data base to facilitate repair bonding. Surface preparation methods including optimized FPL etch, and two hand-clean procedures, phosphoric acid non-tank anodize (PANTA) and PasaJell 105, were evaluated. Bondability and environmental durability of current and on-coming adhesive systems from RT, 250°F, and 350°F cure categories were determined. Autoclave bonds versus vacuum bag bonds were compared.

FOREWORD

This final report summarizes the work accomplished in an "add-on" to Contract F33615-73-C-5171, "Adhesive Bonded Aerospace Standardized Repair Handbook," by the Boeing Commercial Airplane Company, P. O. Box 3707, Seattle, Washington.

Other phases of the basic contract have been reported as follows: Phase I report was a limited distribution document; Phase II–AFML-TR-75-158, AD-A017779; Phase III–AFML-TR-76-65, AD-A035601; Phase IV–AFML-TR-76-201/AFFDL-TR-76-131, AD-A042384; Completed Repair Handbook–AFML-TR-77-206/AFFDL-77-139; Task I of add-on–AFML-TR-78-7.

The add-on work was accomplished under the sponsorship of the Air Force Materials Laboratory (Project 7381/Task 06). Mr. W. Scardino, AFML/MXE, was the project engineer.

Mr. J. E. McCarty was the Boeing Program manager, with Mr. R. E. Horton as project engineer. Mr. M. C. Locke was the principal investigator for the add-on program.

The authors wish to acknowledge the efforts of Mr. R. Z. Mayberry and Mr. K. M. Harriman for the fabrication and testing work, and Mr. J. A. Curtis and Mr. E. A. Ledbury for the SEM analysis.

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SECTION I

INTRODUCTION AND SUMMARY

It was recognized during Phase II of the Repair Handbook Contract (F33615-73-C-5171) that additional studies were required to define and optimize the phosphoric acid non-tank anodize (PANTA) processing conditions. Although excellent durability results were obtained using PANTA as compared to other hand clean methods, the scope of the effort did not permit detailed investigation of critical anodizing parameters. As a result, this supplemental program was conducted to evaluate these variables. Parameters investigated included the effects of anodizing voltage, temperature, time, and rinse delay on bond durability. In addition, bondability of various adhesive system/surface preparation combinations was investigated. The data will form a data base for material selection and facilitate the repair process.

This program consists of two major tasks, as shown in figure 1. Task I was to investigate process variable effects on the phosphoric acid non-tank anodizing (PANTA) procedure. Bond verification tests were included. Task II focused on an evaluation of adhesive/surface preparation combinations, including vacuum bag curing to simulate repairs made under reduced temperature and pressure. The two tasks were performed over a 19-month period. The tasks and program schedule are shown in figure 2. The Task I program results were reported in AFML-TR-78-7 (ref. 1). A synopsis of the results is summarized in Section II.

The work accomplished in Task I consisted of the following:

1. Phosphoric acid non-tank anodize (PANTA) process variables investigation

- Determination of the effects of anodizing potential, temperature, and time
- Determination of the effects of rinse delay time, part size (to 24 x 24 in.), and anodizing mode, i.e., vertical, horizontal, etc.
- A scanning electron microscope (SEM) examination of oxide characteristics
- Evaluation of anodizing clad versus bare
- Anodizing with batteries
- Effect of anodizing over titanium and aluminum fasteners
- Identification of common errors in the application of PANTA

2. Bond verification tests

- Selection of optimum PANTA conditions
- Demonstration of compatibility with adhesive systems

For Task II, the work focused on an evaluation of surface preparation method/adhesive combinations to develop a data base to facilitate repair applications. Task II has been completed and the results are documented in this report. The following work was accomplished in this

task:

1. Surface preparation

- Optimized FPL etch—baseline
- Phosphoric acid non-tank anodize
- PasaJell 105 (non-tank)

2. Adhesive systems

- 250°F cure—AF 127-3, FM 73, EA 9628
- 350°F cure—AF 130, FM 400, FM 300, AF 143
- Room-temperature cure—EA 9320, EA 934

3. Cure conditions

- Autoclave bonds
- Vacuum bag bonds

4. Tests

- Bond strength—lap shear, L/t lap shear, metal-metal peel
- Durability—sustained stressed lap shear, wedge
- Environments—120°F/100% RH, salt spray (5% NaCl, 95°F), -67°F, 180°F, 350°F, room temperature (70-75°F)

No significant differences were noted among the three different surface preparations in their initial, unexposed bond strength. Surfaces prepared with PasaJell 105, however, resulted in reduced bond durability.

Bonds made under vacuum bag cure (reduced temperature and pressure) showed lower bond strength. Reductions in cycles to failure were also found in earlier work (ref. 3) in the vacuum bag bonds as compared to autoclave bonds. This points out an inherent problem in making vacuum bag bonded repairs—reduced strength and durability can be expected. This can be compensated for by keeping the stresses low in the splice bond. The adhesive systems that were tested showed that they are compatible with the evaluated surface preparations.

SECTION II

SYNOPSIS OF TASK I RESULTS*

The purpose of Task I was to investigate the process variables affecting the phosphoric acid non-tank anodize procedure. The effects of varying process parameters on bondability were assessed using the wedge crack extension test. Prior to bonding into wedge test assemblies, anodized surfaces were inspected for interference color, tape tested using 3M Company No. 250 tape, and examined for oxide characteristics with the scanning electron microscope (SEM).

Task I was conducted in two parts. The following processing parameters were investigated in Task I, Part A:

- Effect of voltage variation
- Effect of anodizing temperature
- Effect of anodizing time
- Effect of rinse delay
- Effect of part size
- Anodizing mode
- Dry cell battery anodizing
- Effect of anodizing over titanium and aluminum fasteners
- Identify common errors in PANTA application

Following the processing parameter study, bond verification tests were conducted as Part B of Task I using optimized PANTA surface preparation conditions. For the bond verification tests, both 2024-T3 clad and 7075-T6 bare aluminum adherends were used. Selected adhesive systems from room-temperature cure, 250°F cure, and 350°F cure materials were evaluated.

2.1 PROCESS VARIABLES INVESTIGATION

This part of Task I was aimed at an investigation of the processing parameters that affect the application and bond durability of PANTA-treated surfaces. Specific conclusions and results relating to individual processing parameters were reported in reference 1. Figure 3 shows the typical processing sequence for the Part A investigation. Table 1 shows a summary of the variables and processing conditions investigated. Based on the results of this investigation, including the SEM analysis of oxide characteristics, wedge test, tape test, and color inspection, recommended processing conditions are given. On the basis of the results, the following conditions were selected for the Part B bond verification tests:

- Voltage: 6 volts
- Temperature: 70-80°F

***Reported in AFML-TR-78-7 (ref. 1).**

- Time: 10 minutes
- Rinse delay: less than 5 minutes
- Gelled phosphoric acid, 10-12% concentration: (PR 50 from Products Research)

A brief review of the more critical parameters affecting the PANTA process is given here:

2.1.1 VOLTAGE POTENTIAL

Applied voltages of 1, 2, 4 (baseline), 6, and 10 volts were investigated. Figures 4 and 5 compare the oxide characteristics on 7075-T6 bare and 2024-T3 clad as a function of voltage. It can be seen that oxide uniformity is increased as voltage increases. Little or very thin oxide was formed at 1 volt on 7075-T6 bare aluminum. These surfaces also produced wedge test failures. Figure 6 illustrates the effect of voltage potential on oxide thickness. These results provided the basis for increasing the voltage to 6 volts from the baseline 4 volts (ref. 1).

2.1.2 ANODIZING TEMPERATURE

Two other anodizing temperature conditions were evaluated in addition to ambient room temperature (70°F-80°F). Two temperature extremes (100°F and 40°F) were selected as conditions that may be encountered in repair situations. Wedge test failures were experienced on 100°F, 1- and 2-volt anodized surfaces (both bare and clad) and clad surfaces anodized at 40°F (ref. 1). Due to these sporadic failures, and SEM photomicrographs (see figs. 7-10) of oxides formed at these temperatures, it is recommended that the present process be limited to ambient room-temperature (70°F-80°F) conditions.

2.1.3 ANODIZING TIME

From the baseline 10 minutes, anodizing time was varied to 1, 5, 15, and 20 minutes to determine if shorter or longer times would affect oxide formation and bondability. Both bare and clad wedge specimens showed failure when anodized for 1 minute. Sporadic failures were noted on the clad, 5-minute anodized specimens. No apparent difference was observed on the 15- or 20-minute anodized specimens. The short time (1 to 5 minutes) is inadequate to form environmentally stable oxides (see figs. 11 and 12).

2.1.4 RINSE DELAY

The effects of rinse delay times of 2, 5, and 10 minutes were investigated and compared to no-delay cases. Except for wedge test failures on the 10-minute rinse delay specimens, no other failures were noted. The SEM photomicrographs (figs. 13 and 14) show increasing amounts of loosely adhering oxide to the substrate from no delay to 10 minutes delay. As reported by other investigators (ref. 2), phosphoric acid will dissolve the aluminum oxide formed if the acid is left on the surface after the current is turned off. For optimum processing conditions, no rinse delay or less than 5 minutes rinse delay is recommended.

2.1.5 SUMMARY OF PROCESS VARIABLES INVESTIGATION

Table 1 shows a summary of the variables and processing conditions investigated. Recommended processing limits are given. The results indicated that the phosphoric acid non-tank anodize (PANTA) process can be satisfactorily effected under varying conditions. These include variations in voltage potential (4 to 6 volts), temperature (70°F-80°F), anodizing time (10-15 min), and rinse delay time (0-5 min); over large surfaces (2- x 2-ft); vertical or horizontal surface orientation; over titanium and aluminum fasteners; and using dry cell batteries.

2.2 BOND VERIFICATION TESTS

The purpose of Part B of Task I was to demonstrate process verification of the PANTA procedures and conditions selected from Part A. Table 2 shows the test matrix evaluated on representative room-temperature, 250°F, and 350°F cure adhesive systems. Tests were selected to provide bond strength data, e.g., lap shear, bond durability (sustained stressed lap shear), and compatibility (wedge and metal-metal peel). The comparative bondability performance of clad versus bare aluminum adherends was investigated.

Table 3 illustrates the data summary obtained on the different adhesive/primer systems. No apparent incompatibility in the bond strength or durability exposure on the non-tank anodized surfaces was noted. The optimum anodize conditions used produced environmentally durable bonds and reproducible bonding surfaces.

SECTION III
EVALUATION OF ADHESIVE/SURFACE PREPARATION COMBINATIONS FOR ALUMINUM

This part of the program was aimed at an evaluation of the adhesive/surface preparation combinations for bonded repairs. The objective was to develop a data base on representative room-temperature, 250°F and 350°F cure adhesive systems using three surface preparation methods. These included two hand-clean methods, phosphoric acid non-tank anodize and PasaJell 105, and the optimized FPL etch tank process. Special emphasis was placed on the non-tank anodize method. The other hand-clean method, PasaJell 105, was included because it is used in some Air Logistics Centers (ALC's). Optimized FPL etch (Boeing process specification BAC 5514) was chosen as the baseline on the basis of its current availability at the ALC's.

Adhesive systems evaluated include those in use currently as well as improved durability materials. The tests selected provide a balance of bond strength data and bond durability under environmental exposure.

3.1 SURFACE PREPARATION PROCEDURES

Three surface preparation procedures were selected for evaluation, including one tank immersion and two non-tank methods. The processes were selected on the basis of their current usage at the ALC's or with potential repair bonding applications. The following surface preparation processes were investigated.

- Optimized FPL etch (BAC 5514, tank immersion)
- Phosphoric acid non-tank anodize (PANTA)
- PasaJell 105 (non-tank procedure)

Detailed processing procedures are given in the following paragraphs.

3.1.1 OPTIMIZED FPL ETCH

1. Vapor degrease or solvent clean.
2. Alkaline clean 10 minutes.
3. Rinse 5 minutes in tap water, 110°F minimum.
4. Deoxidize 12-15 minutes at 150°F-160°F in:
   $Na_2Cr_2O_7 \cdot 2H_2O$ - 4.1 to 12.0 oz/gal
   H_2SO_4 66° BE' - 38.5 to 41.5 oz/gal
   Aluminum (2024 bare) - 0.20 oz/gal dissolved aluminum (minimum)
5. Rinse 5 minutes in tap water.
6. Dry at 140°F maximum.

3.1.2 PHOSPHORIC ACID NON-TANK ANODIZE (PANTA)

1. Solvent wipe with MEK, trichloroethane, or equivalent.
2. Abrade with nonwoven abrasive such as nylon abrasive pads or equivalent.
3. Dry wipe with clean gauze to remove dust and debris.
4. Apply a uniform coat of gelled 12% phosphoric acid or PR 50 (gelled phosphoric acid compound can be purchased from Products Research Corporation or made by adding Cab-O-Sil to acid until thickened) to aluminum surface.
5. Place two or three layers of gauze over top of coating; apply another coat of gelled phosphoric acid to completely saturate and wet out the gauze.
6. Secure a piece of stainless steel screen over the coating. Apply another coating of the gelled phosphoric acid.

   NOTE: Be sure that the stainless steel screen DOES NOT CONTACT any part of aluminum surface being anodized.
7. Connect screen as cathode (-) and aluminum as anode (+) as shown in figure 16.

   NOTE: Check this setup before proceeding: screen as cathode (-) and aluminum as anode (+).
8. Apply a DC potential of 6 volts for 10 minutes (4 to 6 volts for 10 to 12 minutes are satisfactory).

   NOTE: A rectifier may be used to supply the voltage and current during anodizing. Current density should be in the range of 1 to 7 amps/sq ft. In an emergency, a fresh or fully charged dry or wet cell battery may be used to anodize small areas.
9. At the end of the anodizing time, open the circuit and remove the screen and gauze.
10. Moisten clean gauze with water. Lightly wipe off the gelled acid with moistened gauze without delay. The rinse delay time is limited to less than 5 minutes. Do not rub the anodized surface. Immersion or spray rinsing should be used if possible.
11. Air dry a minimum of 30 minutes at room temperature or force-air oven dry at 140°F to 160°F.
12. Check quality of prepared surface. A properly anodized surface will show an interference color when viewed through a polarizing filter rotated 90° at a low angle of incidence to fluorescent light or daylight. An inspection being accomplished is shown in figure 17.
13. If no color is observed, repeat steps 4 through 12.

    NOTE: Machined surfaces or abraded surfaces sometimes are difficult to inspect for color. Rotation of the polarizing filter is required because some pale shades of yellow or green are so close to white that without a color-change inspection, they might be considered "no color," which would falsely indicate no anodic coating.

CAUTION: DO NOT TOUCH the dried anodized surface. DO NOT apply tape to the surface.

3.1.3 PASAJELL 105 METHOD

CAUTION: PasaJell 105 can cause severe corrosion when it has been allowed to enter unsealed joints and recesses. Mask those areas prior to use of PasaJell 105. Completely flush the areas to remove all traces of PasaJell 105 after using.

1. Solvent clean with MEK, trichloroethane, or other approved solvent.
2. Abrade with a nylon abrasive pad or 400-grit aluminum oxide abrasive paper.
3. Dry wipe with clean gauze pads.
4. Apply PasaJell 105 to surface with a spatula, brush, or gauze.

   WARNING: WEAR RUBBER GLOVES AND GOGGLES WHEN USING PASAJELL. IF SKIN OR EYES COME IN CONTACT WITH ACID, IMMEDIATELY FLUSH WITH WATER.

5. Leave PasaJell 105 on the surface for 10 to 15 minutes.
6. Wipe off PasaJell. Do not wipe PasaJell onto adjacent areas or crevices or allow it to enter honeycomb core.
7. Dampen a clean gauze pad with clean water and wipe the treated area. Repeat as necessary and check with litmus paper to be sure that all trace of acid has been removed.
8. Allow to air dry before applying primer or bonding.

3.2 ADHESIVE/PRIMER SYSTEMS

Adhesive/primer systems were selected for evaluation on the basis of their applicability for repairs and current or future utilization at the ALC's. Three categories of adhesive materials were evaluated:

- 250°F cure–AF 127-3, FM 73, EA 9628, all on BR 127 CIAP primer
- 350°F cure–AF 130/EC 2333, FM 400/BR 400, FM 300/BR 127, AF 143/EC 3917
- Room-temperature cure–EA 9320, EA 934, with BR 127 CIAP primer

These adhesive systems provide a representative spectrum of repair materials currently in use (e.g., AF 127-3 at San Antonio ALC, AF 130 at Sacramento ALC) and upcoming systems. The latter include high-durability 250°F cure adhesives such as FM 73 and EA 9628 or 350°F cure systems such as AF 143. The FM 300 material, a 350°F cure adhesive, is being considered to fill the gap for service temperatures between 180°F and 300°F.

3.3 CURE CONDITIONS

Both autoclave cure bonds and vacuum bag cure bonds were evaluated. The vacuum bag cures were made to simulate repair cure conditions under reduced temperature and pressure. The cure conditions shown in table 4 were investigated for the adhesive/primer systems studied.

3.4 250° CURE ADHESIVE SYSTEMS–AUTOCLAVE BONDS

Table 5 identifies the test matrix used to evaluate 250°F cure adhesive system, autoclave bonded panels. The adhesive systems include one presently used for repairs at the ALC's (AF 127-3) and two new, improved durability systems (FM 73 and EA 9628). In all cases, corrosion-inhibiting adhesive primer (BR 127) was used.

Following surface preparation and priming on the aluminum adherends, the panels were bonded into wide-area (24- x 24-in.) lap shear, peel (14- x 17-in.), and wedge (6- x 6-in.) assemblies. Panel and specimen configurations for lap shear, peel, and wedge assemblies are shown in figures 18, 19, and 20.

Tables 6, 7, and 8 summarize the results obtained with AF 127-3, FM 73, and EA 9628. The effects of surface preparation are compared for each adhesive system.

No significant differences were found in the mechanical strength, i.e., stressed lap shear or peel tests, among the three different surface preparation methods. All three adhesive systems showed similar trends.

Test temperature had a significant effect on the bond strength properties. As shown in the figures 21, 22, and 23 L/t lap shear plots, tests at 180°F showed shear strength reductions in all cases. In comparison, a slight increase for the 1/2-in. overlap shear test was noted at -67°F. This trend was observed on all three adhesive systems and the three surface treatments. The characteristic behavior of modified epoxy materials to undergo visoelastic changes probably is responsible for the increased ultimate failure load of the 0.5-inch lap tests at -67°F. However, at the longer overlaps (1 and 2 in.), the influence of peel at the bond joint load-transfer edge prevents this trend from continuing. The -67°F values at these lap lengths therefore are nearly the same as the room-temperature values.

While the mechanical bond strengths were not significantly affected by the surface preparation methods, the bond durability under environmental conditions as evaluated by the wedge test was affected. Under an opening mode stress on the bondline, the influence of surface preparation is significantly demonstrated by the crack extension. The crack extension increased rapidly for PasaJell 105 bonds, particularly with FM 73 and EA 9628, as shown in tables 6, 7, and 8. It was less affected on the AF 127-3 system. Figure 24 illustrates the crack growth characteristics for the three adhesives and three surface treatment methods. Failure modes on the PasaJell 105 were 100% adhesive at the adherend interface. Cohesive failure or center-of-the-bond failure modes were observed on the optimized FPL and PANTA bonded specimens.

Bonded specimen failure surfaces are shown in figures 25 through 33 for the three adhesive systems and three surface preparation methods. Comments regarding the mode of failure are as follows:

- AF 127-3 System

  Figures 25, 26, and 27 for optimized FPL etch, PANTA, and PasaJell 105, respectively. All show cohesive failures except for PasaJell 105 wedge crack specimens after exposure with 100% interfacial or adhesive failure.

- FM 73 System

  Figures 28, 29, and 30 for optimized FPL etch, PANTA, and PasaJell 105, respectively. All show cohesive failures except for PasaJell 105 wedge specimens with 100% adhesive failure after 4 hours exposure.

- EA 9628 System

  Figures 31, 32, and 33 for optimized FPL etch, PANTA, and PasaJell 105, respectively. All show cohesive failures except for PasaJell 105 wedge specimens with 100% adhesive failure after 4 hours exposure.

The intent of the developed data is to serve as a basis for selecting material systems and surface preparation methods for repair bond with consideration for subsequent environmental durability. The latter is important because only certain tests shown environmental stability for bonds as influenced by processing variables. This was clearly demonstrated on the wedge tests with bonds made on PasaJell 105 treated surfaces.

As a further comparison to the wedge test results, metal-to-metal peel specimens (FM 73 adhesive) were tested in the dry/wet conditions using the "Bell" peel method. Figures 34, 35, and 36 are the test charts for these tests. Note that no difference was observed in the peel strengths on the optimized FPL etch and PANTA specimens tested dry and wet. However, on the PasaJell 105 specimen, the peel strength dropped to nearly zero when tested wet, with 100% adhesive, interfacial failure. Similar failure modes were encountered on the wedge specimens, as shown in figures 28, 29, and 30. Although on certain adhesive systems, e.g., AF 127-3, the environmental durability results were less affected by the PasaJell 105 treatment, in general, the peel test and the wedge test demonstrated the lack of environmental durability on bonds made with PasaJell 105 treated surfaces.

3.5 250°F CURE ADHESIVE SYSTEMS–VACUUM BAG BONDS

The test matrix for this task is shown in table 9. L/t lap shear tests at room temperature, 180°F, and -67°F and stressed lap shear tests were run on the vacuum bag bonded specimens. It was felt that these tests would be adequate to provide a comparison to autoclave bonds, which were used as a baseline. The vacuum bag bonds were made under reduced temperature and pressure, as shown in section 3.3, to simulate repair situations. The 200°F cure temperature reflects repair practice to stay below the original bond cure temperature to avoid possible thermal degradation of the initial bond. The vacuum bag pressure (23-28 in. Hg) represents vacuum heat blanket capability.

The adhesive systems and surface preparations were the same as those used for the autoclave cured bonds. Tables 10, 11, and 12 summarize the test results, and the L/t versus test temperature data are plotted in figures 37, 38, and 39. A slight reduction in the bond strengths occured on the PasaJell 105 specimens for all adhesive systems. This reduction is also noted on the sustained stressed lap shear tests. The latter were residual strengths determined on specimens after the 60-day sustained stressed exposure. None of the specimens experienced any failure within the 60-day exposure time.

Failure surfaces are shown in figures 40 through 48 for the three adhesive systems and three surface treatments. Generally, failure modes were cohesive, center-of-the-bond type. Some instances of adhesive-primer failure were observed on the longer (2 in.) overlap specimens, particularly when tested at -67°F. This type of failure was more prominent on the PasaJell 105 specimens than on the FPL etched or PANTA specimens. This correlates to the marginal surface preparation results using PasaJell 105 on wedge and peel specimens.

A comparison was made between the vacuum bag bonds and the autoclave bonds. A reduction in shear strength was found in all cases on vacuum bag bonds. The reduced cure temperature and pressure resulted in a strength reduction ranging from 5% to 15%. This reduction was also noted in the PABST repair program (ref. 3), in which a significant reduction in cycles to failure was found on vacuum bag bonds versus autoclave bonds. The design of repair bonds made under vacuum bag conditions must consider this reduction. The effect of the quality of the surface treatment used also must be considered.

3.6 350°F CURE ADHESIVE SYSTEMS–AUTOCLAVE BONDS

The test matrix for this task is shown in table 13. Four 350°F cure systems were evaluated including AF 130, FM 400, AF 143, and FM 300. All systems are intended for elevated-temperatuer service to 350°F except for FM 300. The latter is a new adhesive being considered to fill the service temperature gap between 180°F and 300°F. The FM 300 system has improved toughness, i.e., higher peel strength, compared to the other 350°F cure systems evaluated.

As in earlier tasks with 250°F cure systems, three surface preparation methods were evaluated. Optimized FPL etch served as the baseline with PANTA and PasaJell 105 as the hand-clean methods. Mechanical strength tests and stressed durability tests were conducted.

Tables 14, 15, 16, and 17 summarize the results of this evaluation. Except for FM 300, all showed the characteristic low peel, low toughness typical of 350°F cure systems used for high-temperature applications. Further, all except FM 300 were unaffected by the elevated test temperature (350°F). Since the FM 300 was designed for a service temperature range of 180°F to 300°F, additional tests were run at 250° and 300°F to determine the effect of temperature. Also, since BR 127 CIAP primer (a 250°F curing system) was used with this system, tests were run with and without BR 127 to evaluate the degradation of the CIAP primer at high temperatures. These results are plotted in figures 49 and 50. The shear strength showed a significant dropoff from 250°F to 350°F. Lower values were obtained on the unprimed specimens. With both primed and unprimed specimens, higher values were obtained on the anodized surfaces than on the optimized FPL etch surfaces.

Failure surfaces of representative specimens are shown in figures 51 through 62 for the four adhesive systems and three surface treatments. General comments about the failure modes and comparative bond durability are given below.

- AF 130/EC 2333 System

  Figures 51, 52, and 53 show bonded surfaces for optimized FPL etch, PANTA, and Pasa-Jell 105 specimens, respectively. Mixed failure modes were observed on these specimens. Most specimens had cohesive failures, i.e., center of the bond or near the adhesive-primer interface. A few "slick" failures were noted on -67°F test specimens on all three surface preparations. Comparable results were obtained with all three surface treatments.

- FM 400/BR 400 System

  Typical failures modes of tested specimens are shown in figures 54, 55, and 56. Mixed failure modes were common with this adhesive system. Some "slick" failures had primer-adhesive on the surface. Again, no significant differences in the test results were found among the three surface preparations, including the stressed lap shear and wedge tests. Large scatter in the data is evident from the large standard deviations shown in table 15.

- FM 300/BR 127 System

  Figures 57, 58, and 59 show typical failure surfaces for optimized FPL, PANTA, and Pasa-Jell 105 treated specimens. Failure modes were mostly cohesive, center of the bond, or at the primer-adhesive interface. Failure surfaces on specimens tested at 350°F showed apparent softening of the adhesive not observed on the other 350°F adhesive systems. The 350°F test results were extremely low. It was due to these results that additional tests were run at 250°F and 300°F (see figs. 49 and 50) to determine the effect of temperature. A definite reduction can be seen in figures 49 and 50 in the temperature range of 250°F to 350°F. Again, no significant difference was noted among the three surface preparations.

- AF 143/EC 3917 System

  Figures 60, 61, and 62 show the typical failure bond surface of specimens tested under various conditions for optimized FPL etch, PANTA, and PasaJell 105, respectively. As with the other adhesive systems, mixed failure modes were observed. Most failures were cohesive except for some "slick" type adhesive failures for the -67°F tests. In general, the test results showed less scatter than with the AF 130 or FM 400 systems. Some improvement in toughness is seen in the peel test values. Except for the peel values, results comparable to FM 400 were obtained.

3.7 350°F CURED ADHESIVE SYSTEMS—VACUUM BAG BONDS

The test matrix for this task is shown in table 18 with three adhesive systems evaluated under vacuum bag bond conditions. The cure temperatures and pressures are shown in table 4. The primary emphasis was to simulate repair conditions where vacuum heating blankets may be used and the cure is to be made at reduced temperatures. Test results are shown in tables 19, 20, and 21 for AF 130, FM 400, and AF 143, respectively.

A slight reduction in the bond strength was observed for the vacuum bag cured AF 130 and FM 400 specimens as compared to the autoclave bonds. No difference was noted on the AF 143 specimens. On the basis of these results, it appears that the 300°F cure was adequate to cure the bonds and vacuum bag pressure was satisfactory.

Typical bond failure surfaces are shown in figures 63 through 71. General comments regarding failure modes are noted below.

- AF 130 System

  Figures 63, 64, and 65 show the bond failure surfaces for optimized FPL etch, PANTA, and PasaJell 105, respectively. As seen previously in the autoclave bond specimens, mixed failure modes were observed on these specimens. The adhesive on the AF 130 seemed to separate from the carrier often. A few "slick" type failures were noted on the -67°F tests. Even these appeared to have polymer adhesive on the adherend surface.

- FM 400 System

  The bond failure surfaces are shown in figures 66, 67, and 68 for the three surface preparations. Generally, failure modes were similar to the autoclave bonds where mixed modes (cohesive and adhesive) were observed. Typically, the longer overlap length (1- and 2-in.) specimens showed larger amounts of adhesive-type failure, near the load transfer tips. No significant differences were found among the different surface preparations, although in some cases a little reduction was shown on PasaJell 105 specimens.

- AF 143 System

  Figures 69, 70, and 71 show the bond failure surfaces on the three surface preparations evaluated. Failure modes were similar to the autoclave bond specimens. Test results showed similar trends as for autoclave bonds when compared for each surface preparation (see tables 17 and 21). The 300°F cure appears to be satisfactory in fully curing the adhesive. The test results showed no significant difference in vacuum bag pressure bonded specimens.

3.8 ROOM-TEMPERATURE CURE ADHESIVE SYSTEMS

Table 22 identifies the test matrix used to evaluate two RT cure adhesive systems. EA 9320 is intended for lower service temperature (less than 180°F) applications, and EA 934 is used for higher temperature service. Both adhesive systems are used for repairs at various facilities.

Following surface preparation, BR 127 CIAP primer was applied to all bonding surfaces. Wide-area (24- x 24-in.) lap shear assemblies, metal-metal peel (14 x 17 in.) and wedge assemblies (6 x 6 in.) were fabricated. A positioning fabric, Monsanto Cerex 3603-23, was used to control bondline thickness. Curing was accomplished under vacuum bag pressure (approximately 20-27 in. Hg). Panel and specimen configurations are as shown in figures 18, 19, and 20.

Tables 23 and 24 summarize the results obtained with EA 9320 and EA 934, respectively. The effects of surface preparation, test temperature, and test environment are compared. Both ad-

hesive systems showed the characteristic reduction in mechanical bond strengths when tested at elevated temperature. Also, EA 934 showed its brittle behavior or lower toughness in the peel strengths and the initial crack lengths in the wedge specimens.

Due to the large amount of scatter in the data and the appearance of "adhesive-starved" bondlines, additional specimens were made and retested for comparison. As shown in figure 72, typical bondline thicknesses of the original specimens were measured to be 4-6 mils. The retest specimens had bondline thicknesses of approximately 10-12 mils. Generally, improved bond strengths were obtained on the thicker bondline specimens. It should be pointed out, however, that in fabricating the assemblies, much difficulty was encountered in an attempt to achieve uniform, void-free bonds. This is especially true for the larger panels such as the wide-area lap shear or metal-metal peel (24 x 24 in. or 14 x 17 in.).

Failure surfaces of typical specimens are shown in figures 73 through 78 for the three surface preparation methods and two adhesive systems. Some general comments on the failure modes are discussed below.

- EA 9320 System

  Figures 73, 74, and 75 show bonded surfaces of typical specimens after test from optimized FPL etch, PANTA, and PasaJell 105 treatments. Nearly all specimens had cohesive failure modes with a few specimens failing near the primer-adhesive interface on the -67°F tests. Some reduction in bond strength and durability on the PasaJell 105 specimens was observed. This is obvious in the peel and stressed lap shear residual strength tests (see table 23). Data on the optimized FPL etch and PANTA treated surfaces appeared similar.

- EA 934 System

  Typical bond failure surfaces are shown in figures 76, 77, and 78 for the three surface preparations evaluated. As with EA 9320, mixed failure modes were observed with most of the specimens exhibiting cohesive failures. Few primer-adhesive failures were observed on the -67°F tests and wedge specimens. No significant difference was found in the test results.

3.9 SUMMARY OF ADHESIVE/SURFACE PREPARATION COMBINATIONS

Based on the results of this task, the following general summary is concluded:

- Surface Preparation

• Optimized FPL Etch	Satisfactory
• Phosphoric Acid Non-Tank Anodize	Satisfactory
• PasaJell 105	Reduced bond strength and durability when used with the 250°F cure adhesive systems

• Cure Conditions	
• Autoclave Bonds	Satisfactory
• Vacuum Bag Bonds	Reduced bond strength
• Adhesive Systems	
• 250°F Cure	All compatible with
• 350°F Cure	surface preparation
• RT Cure	and cure conditions

SECTION IV

CONCLUSIONS

Work accomplished in this program resulted in the following general conclusions. Specific conclusion relating to individual tasks have been presented in sections II and III and in the Interim Report (ref. 1).

- The phosphoric acid non-tank anodize (PANTA) process was evaluated over varying conditions of voltage potential, temperature range, anodizing time, and rinse delay time. Extreme high or low anodizing temperatures, long rinse delay time, short anodizing time, or low voltage potential produced sporadic bond failures.

- The PANTA surface treatment produced durable bonds on clad or bare aluminum alloys; on surfaces oriented in various positions, e.g., vertical or overhead; using dry cell batteries; and over large surfaces (2 x 2 ft.).

- Of the three surface treatments evaluated, phosphoric acid non-tank anodize (PANTA) showed overall better performance than PasaJell 105, and comparable results to optimized FPL etch (tank process) when used with the 250°F cure adhesive systems. Comparable results were obtained with all three surface treatments when they were used with the R.T. and the 350°F cure adhesives.

- No incompatibility was observed with the adhesive systems evaluated on the three surface treatments and cure conditions.

- Vacuum bag bonds exhibited reduced bond strength and durability as compared to autoclave bonds.

- SEM analysis of oxide characteristics showed that optimum non-tank anodizing conditions produced environmentally stable oxide with good bond durability.

TASK I PHOSPHORIC ACID NON-TANK ANODIZE FOR ALUMINUM

- **PROCESS VARIABLE INVESTIGATION**
- **VERIFICATION BONDING TESTS**

TASK II EVALUATION OF ADHESIVE/SURFACE PREPARATION COMBINATIONS FOR ALUMINUM

- **AUTOCLAVE CURE 250° F AND 350° F ADHESIVE SYSTEMS**
- **RT CURE ADHESIVE SYSTEMS**
- **VACUUM BAG BONDING**

Figure 1.—Add-On Program Tasks

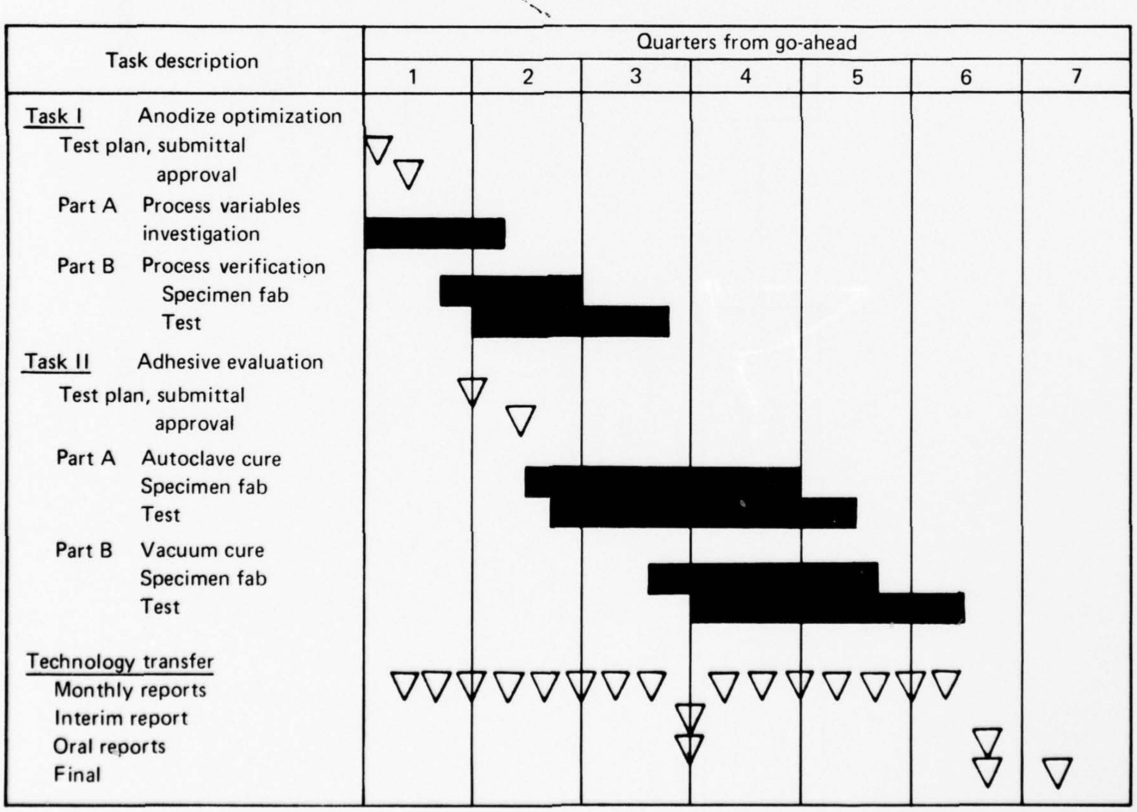


Figure 2.—Program Schedule

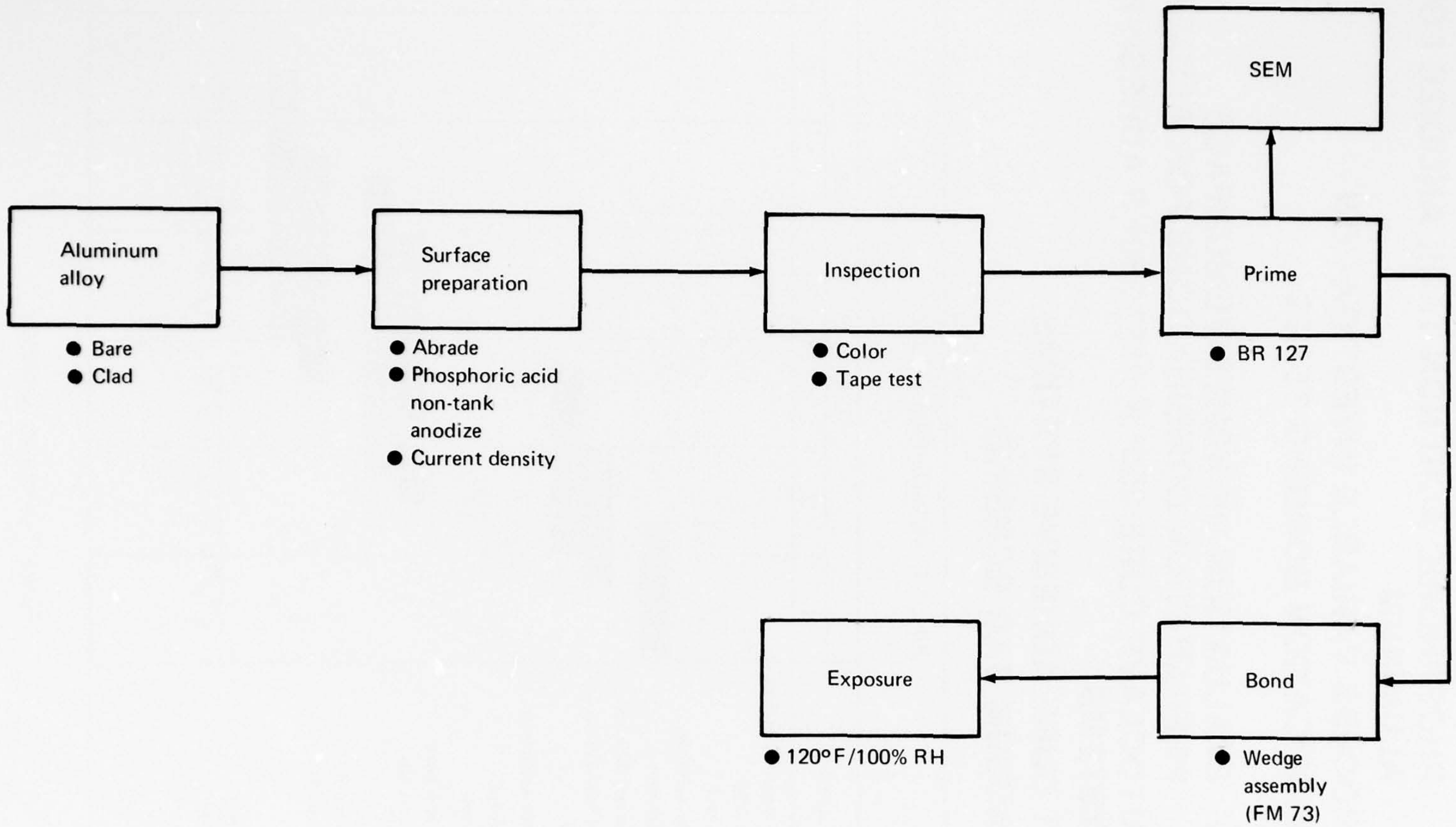


Figure 3.—Typical Processing Sequence

Phosphoric acid non-tank anodize 7075-T6 Bare 5000X

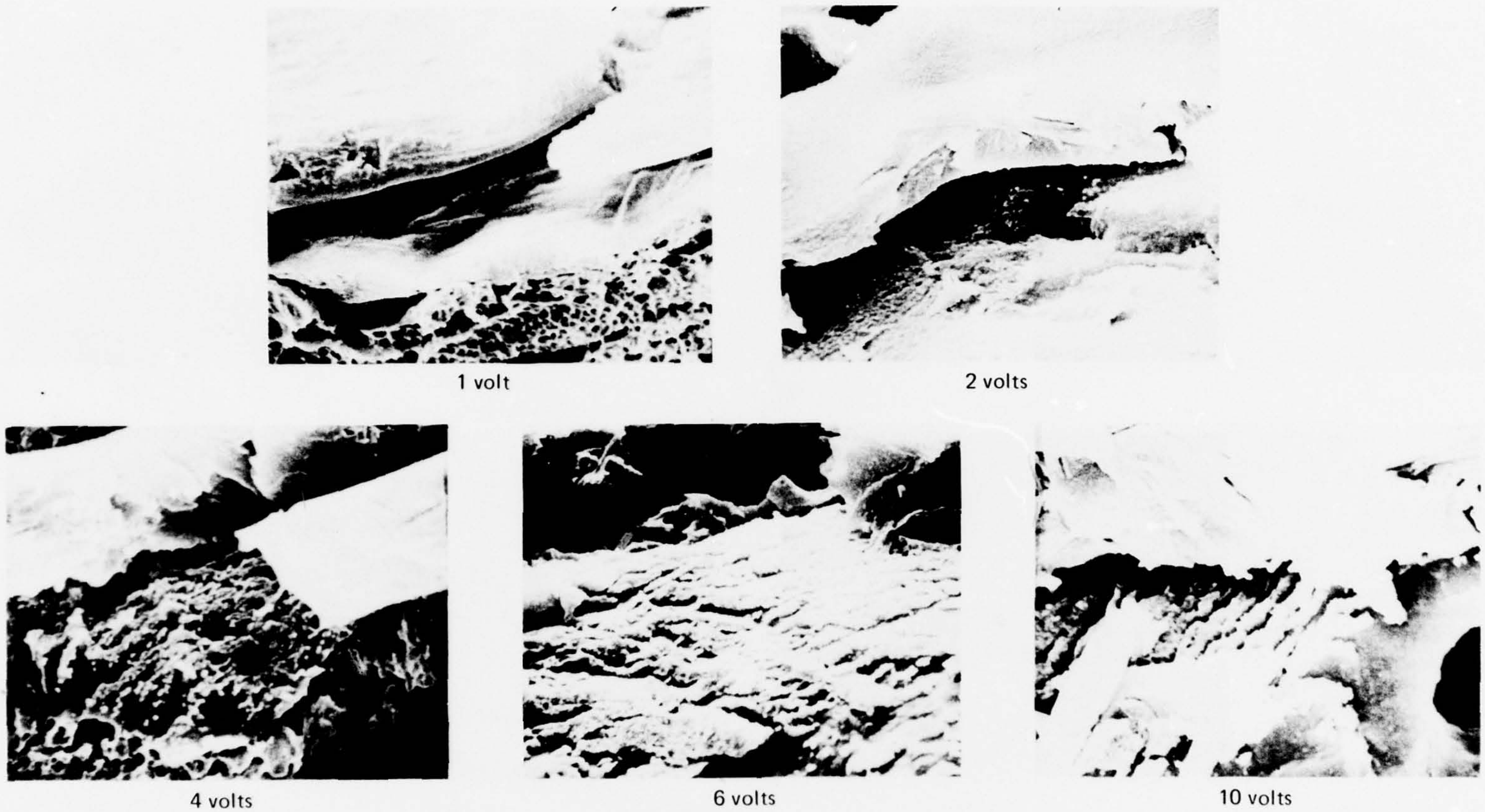


Figure 4.—SEM Photomicrograph of Oxide as a Function of Voltage— 7075-T6 Bare

Phosphoric acid non-tank anodize 2024-T3 Clad 5000X

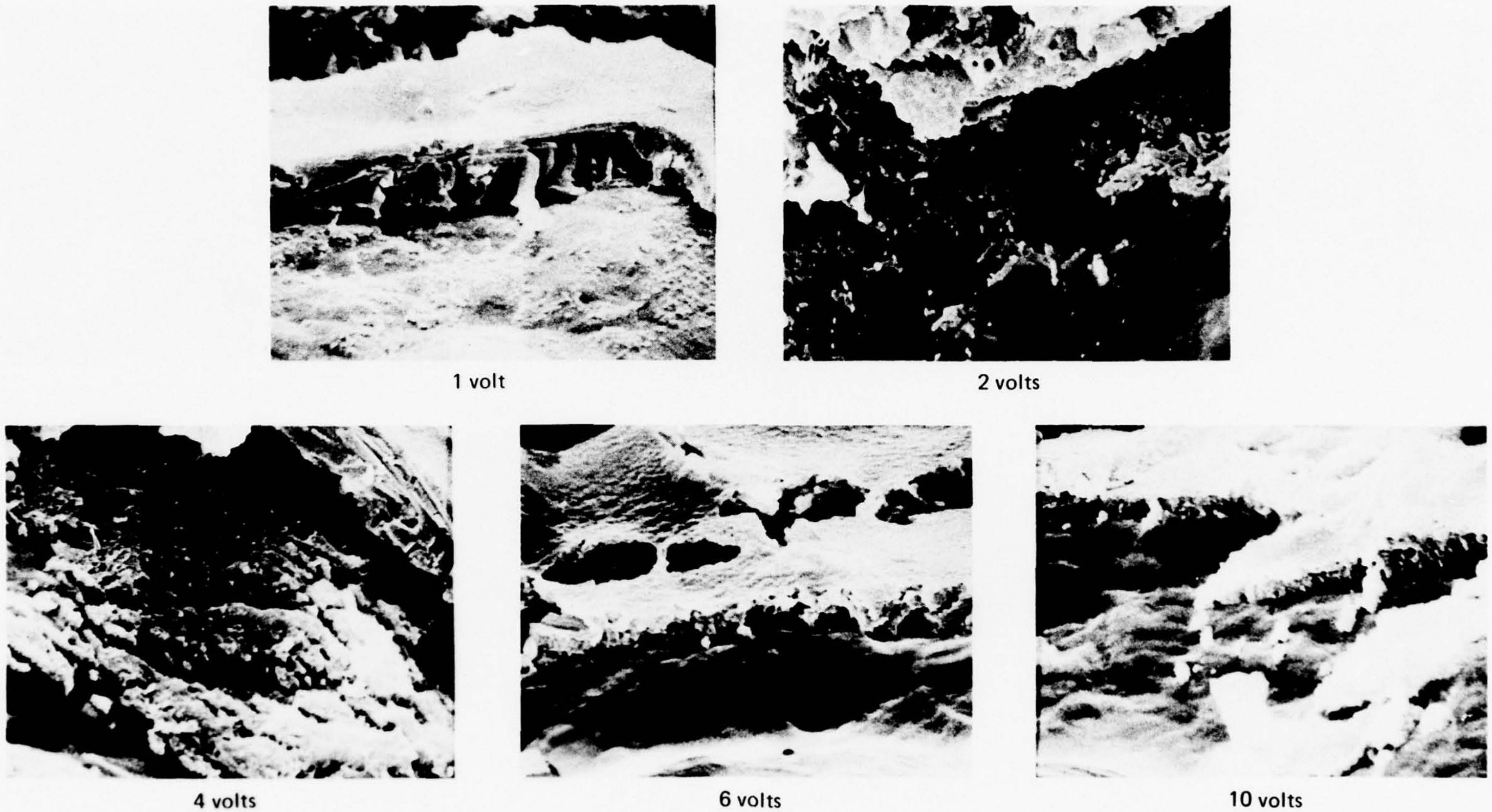


Figure 5.—SEM Photomicrograph of Oxide as a Function of Voltage—2024-T3 Clad

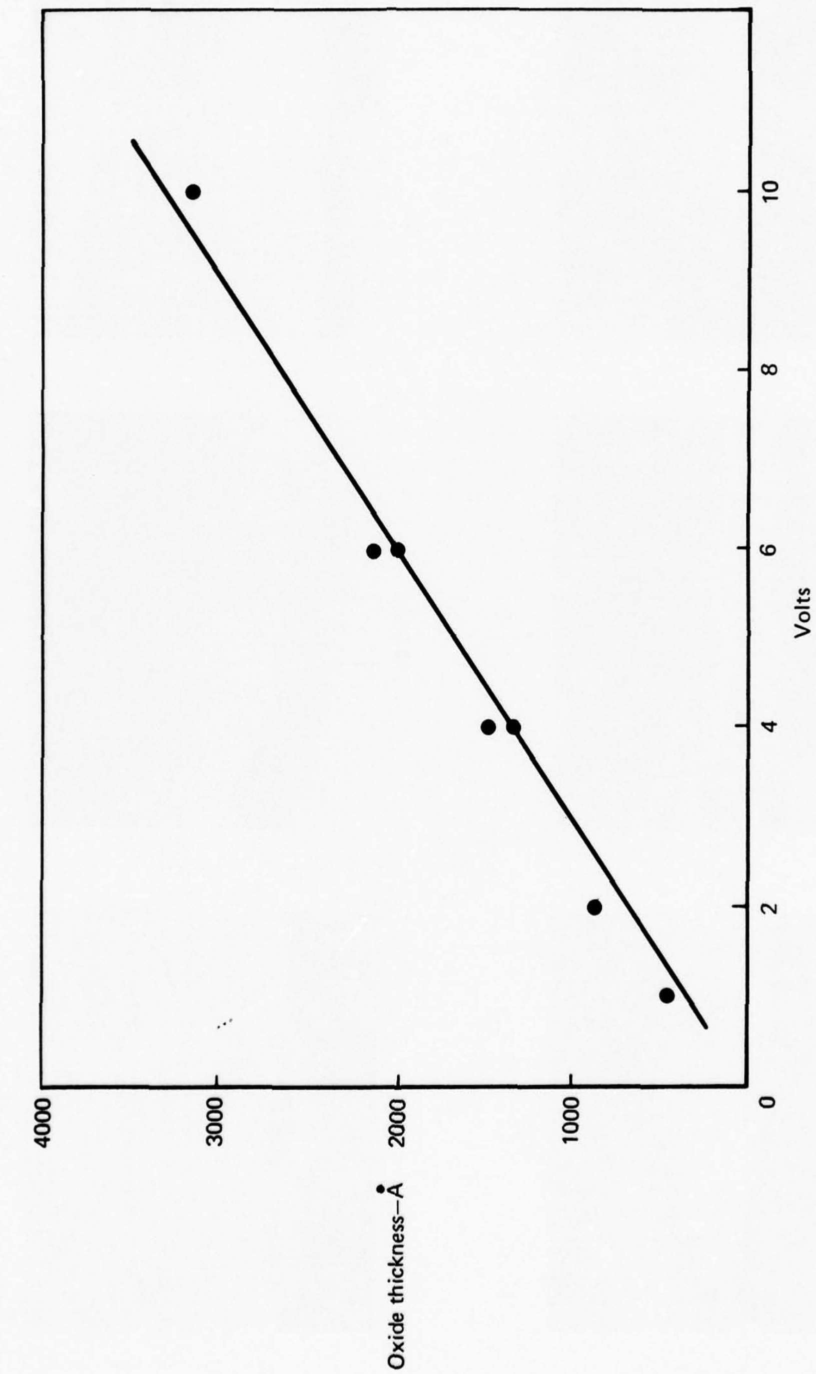


Figure 6.—Oxide Thickness verses Voltage Variation

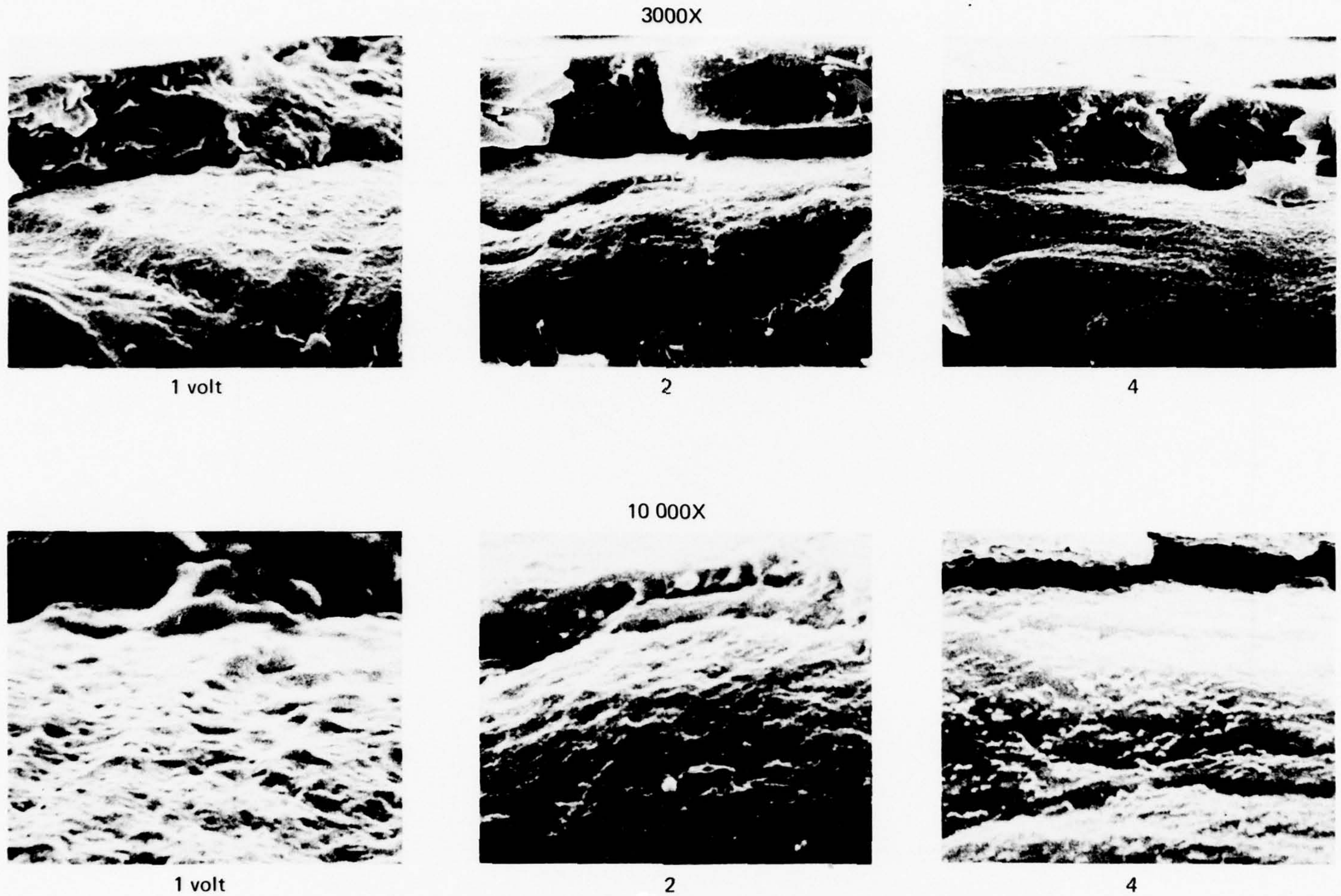


Figure 7.—SEM Photomicrograph—Anodized at 100 °F—7075-T6 Bare

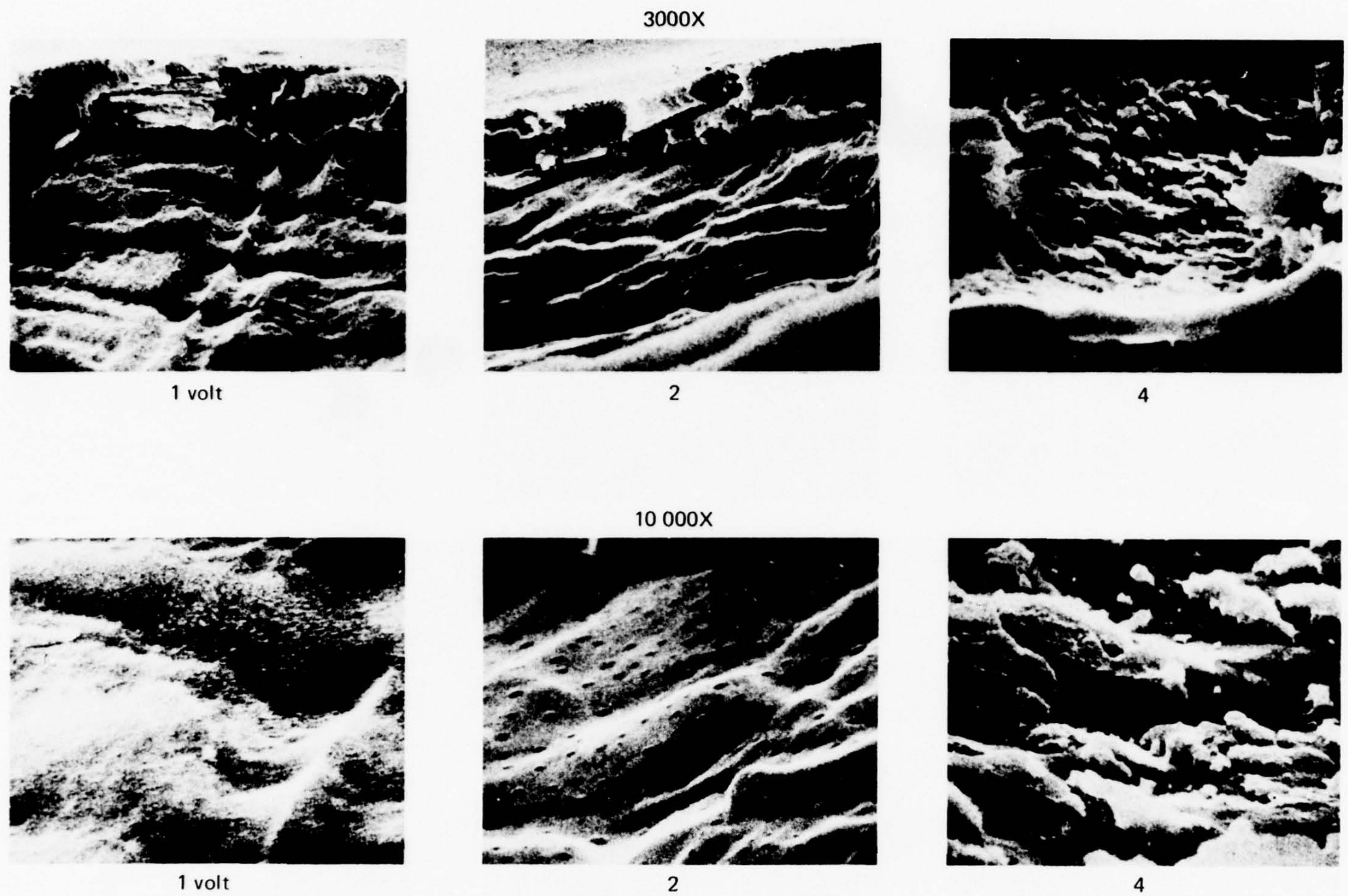


Figure 8.—SEM Photomicrograph—Anodized at 100 °F—2024-T3 Clad

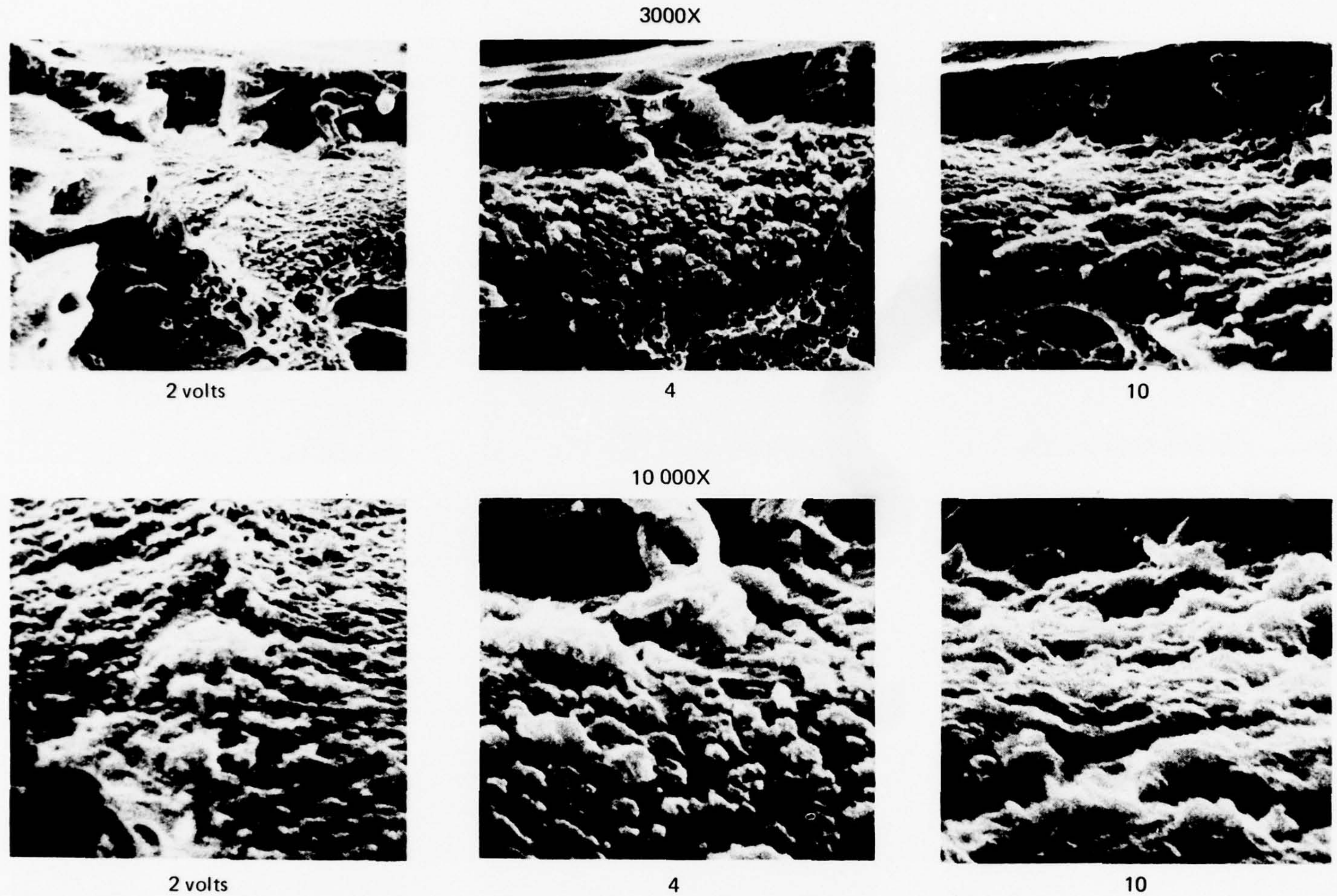


Figure 9.—SEM Photomicrograph—Anodized at 40 ° F—7075-T6 Bare

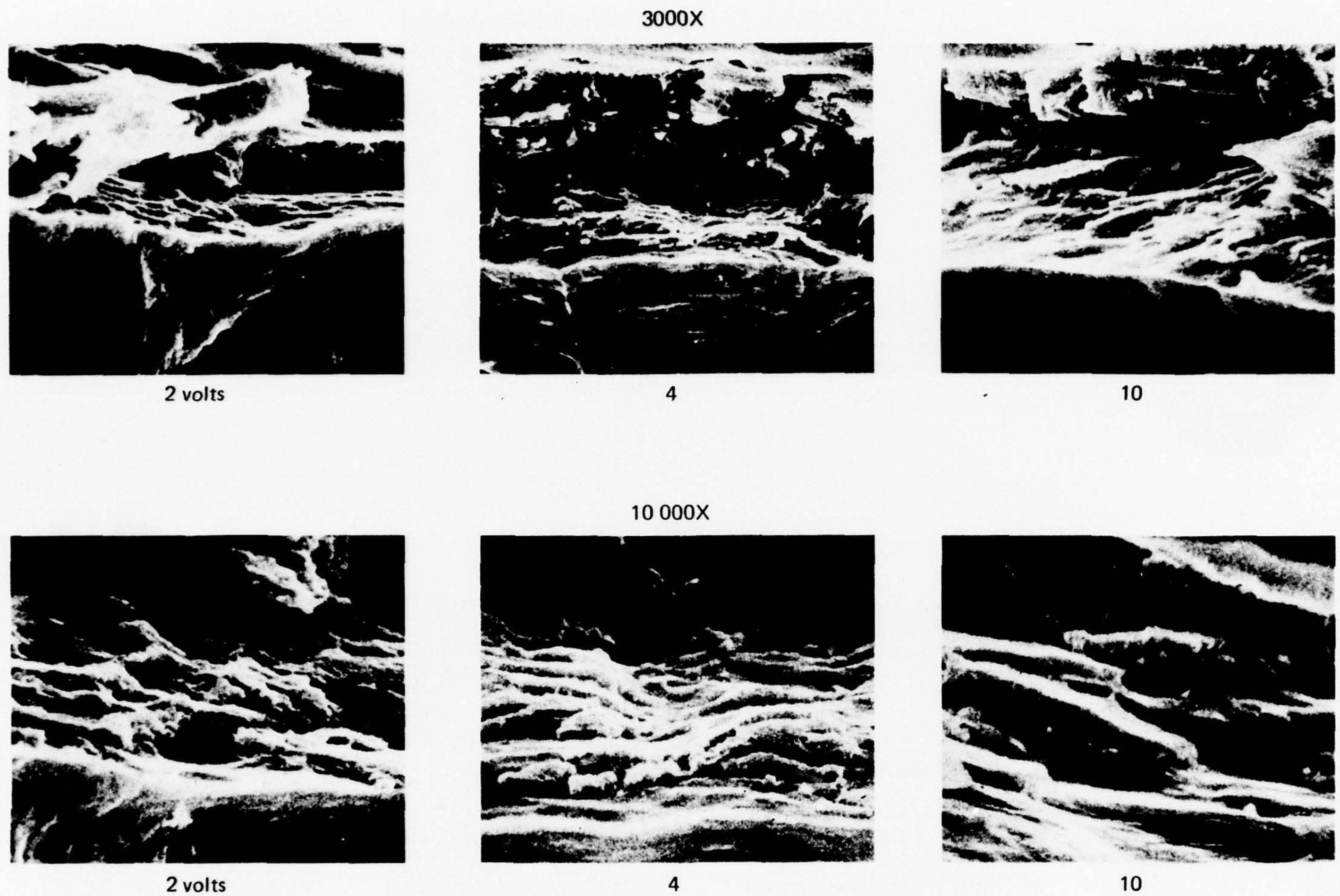


Figure 10.—SEM Photomicrograph—Anodized at 40 °F—2024-T3 Clad

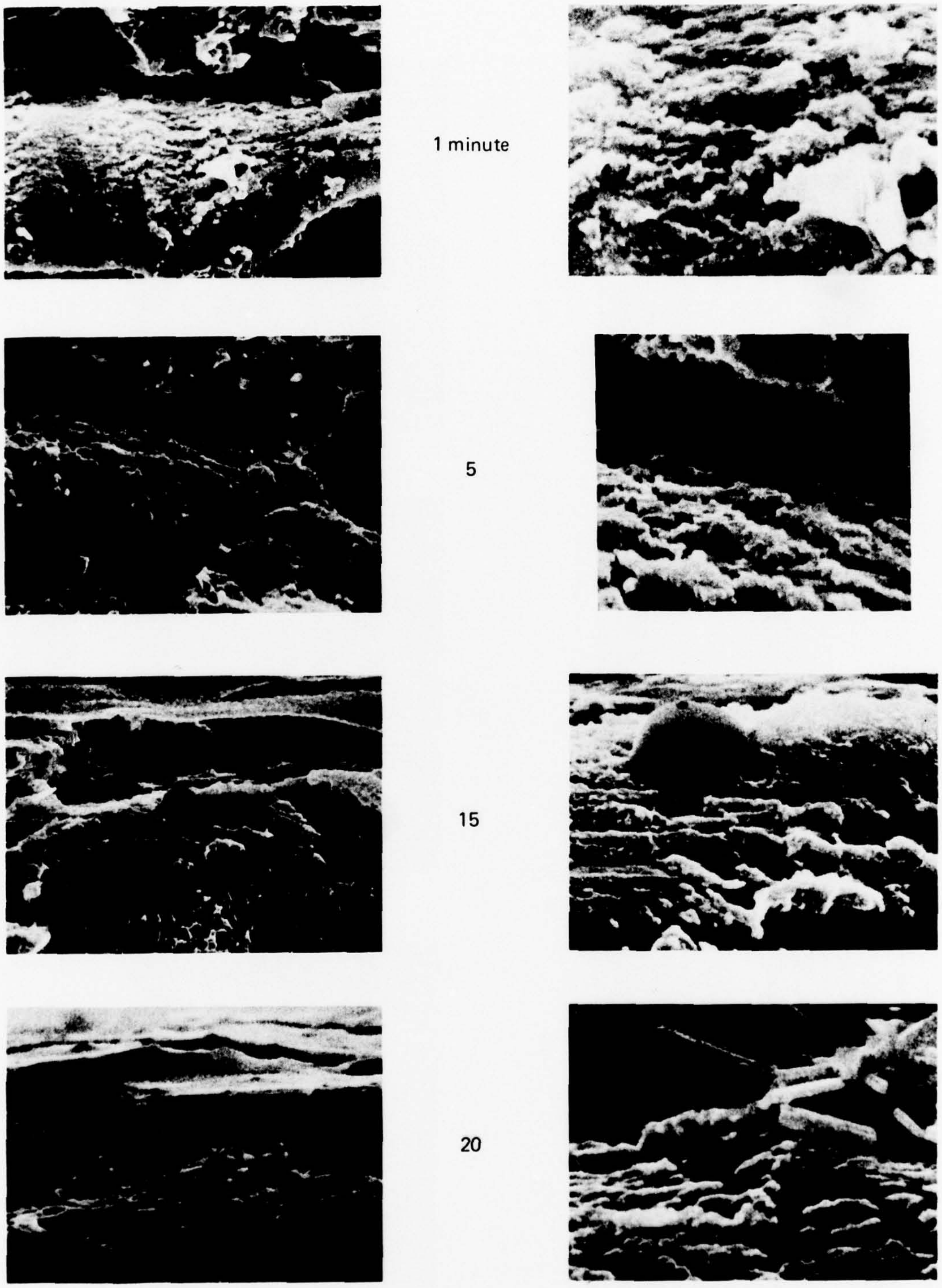


Figure 11.—SEM Photomicrograph—Anodize Time Variation—7075-T6 Bare

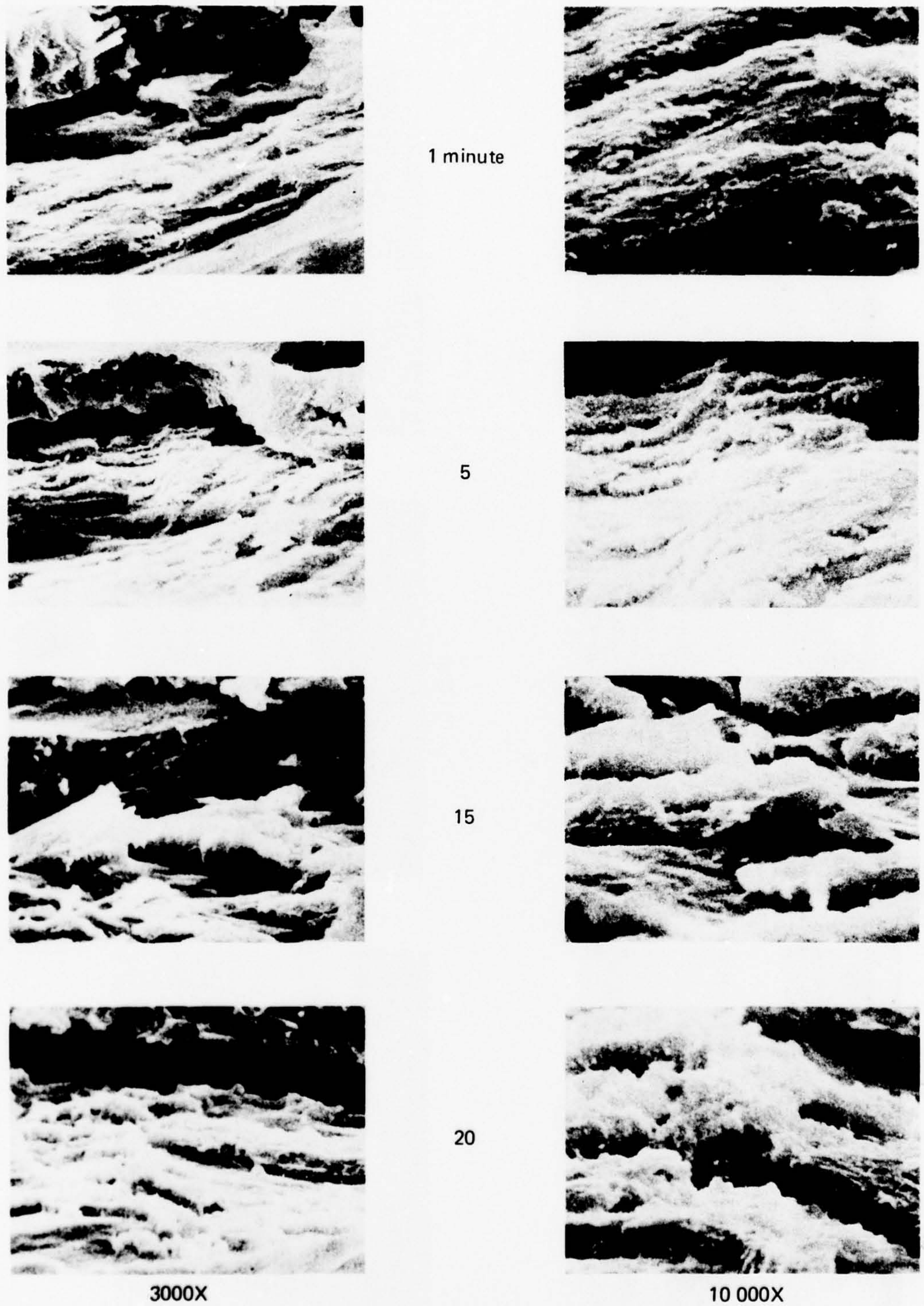


Figure 12.—SEM Photomicrograph—Anodize Time Variation—2024-T3 Clad

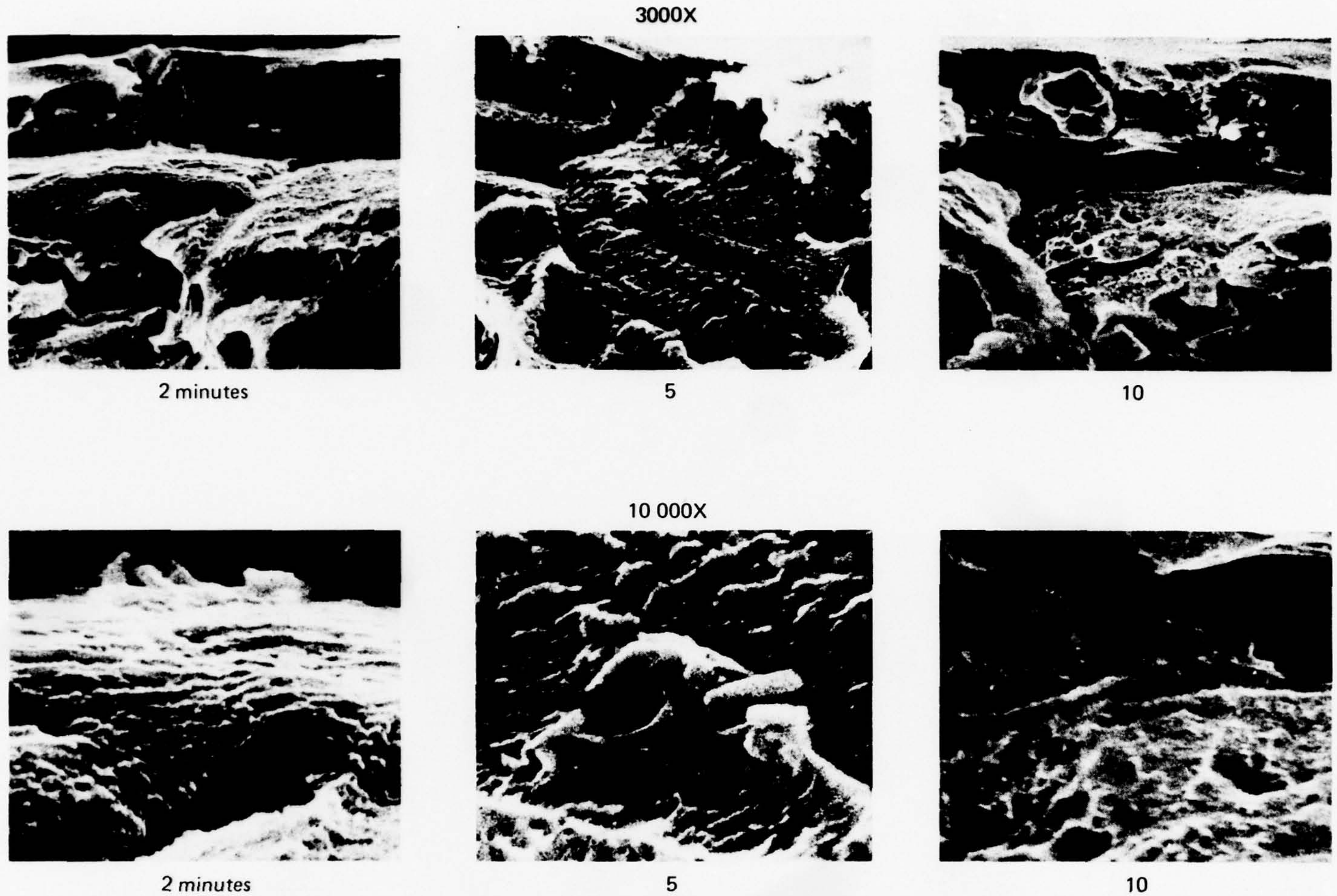


Figure 13.—SEM Photomicrograph of Rinse Delay Time—7075-T6 Bare

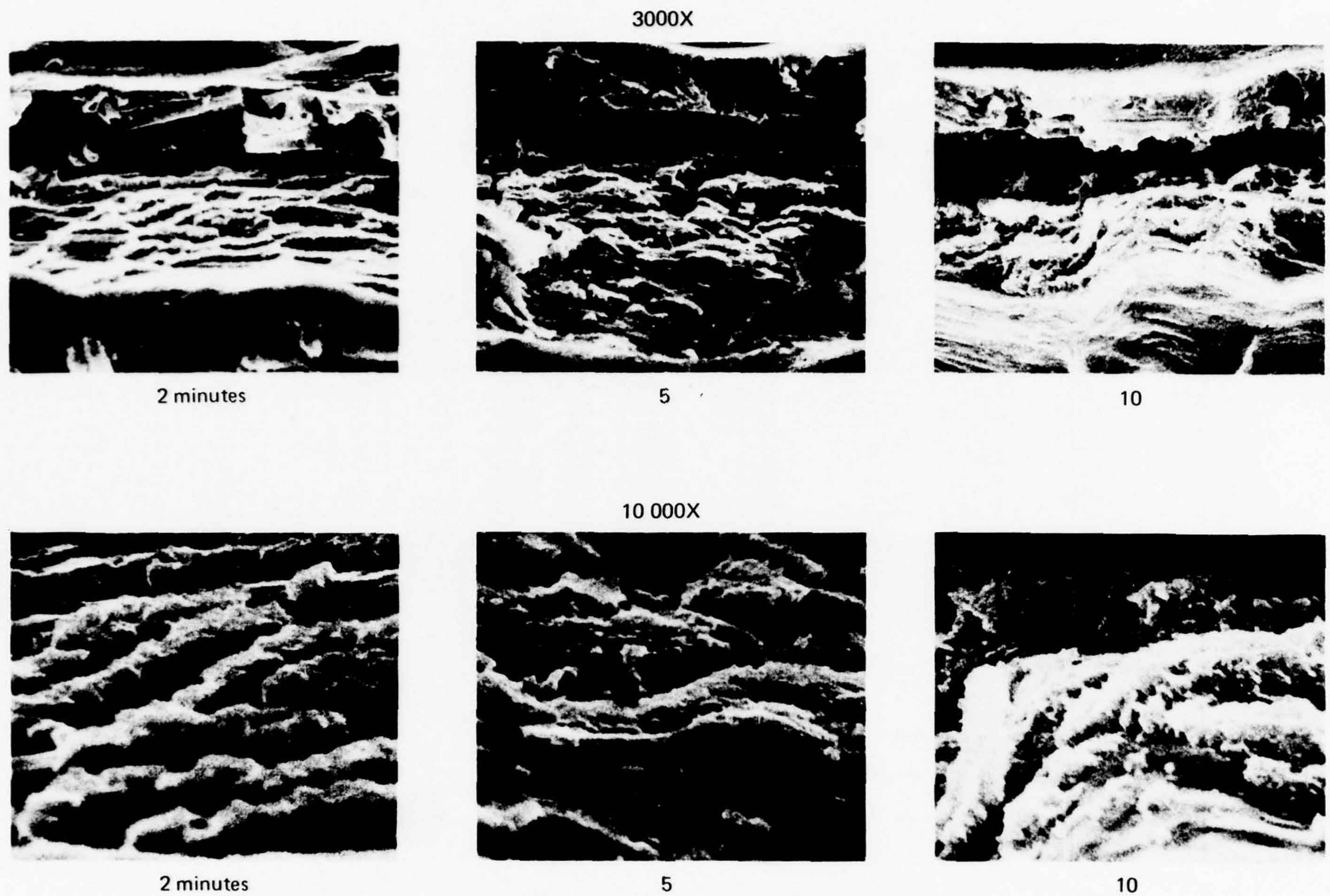


Figure 14.—SEM Photomicrograph of Rinse Delay Time—2024-T3 Clad

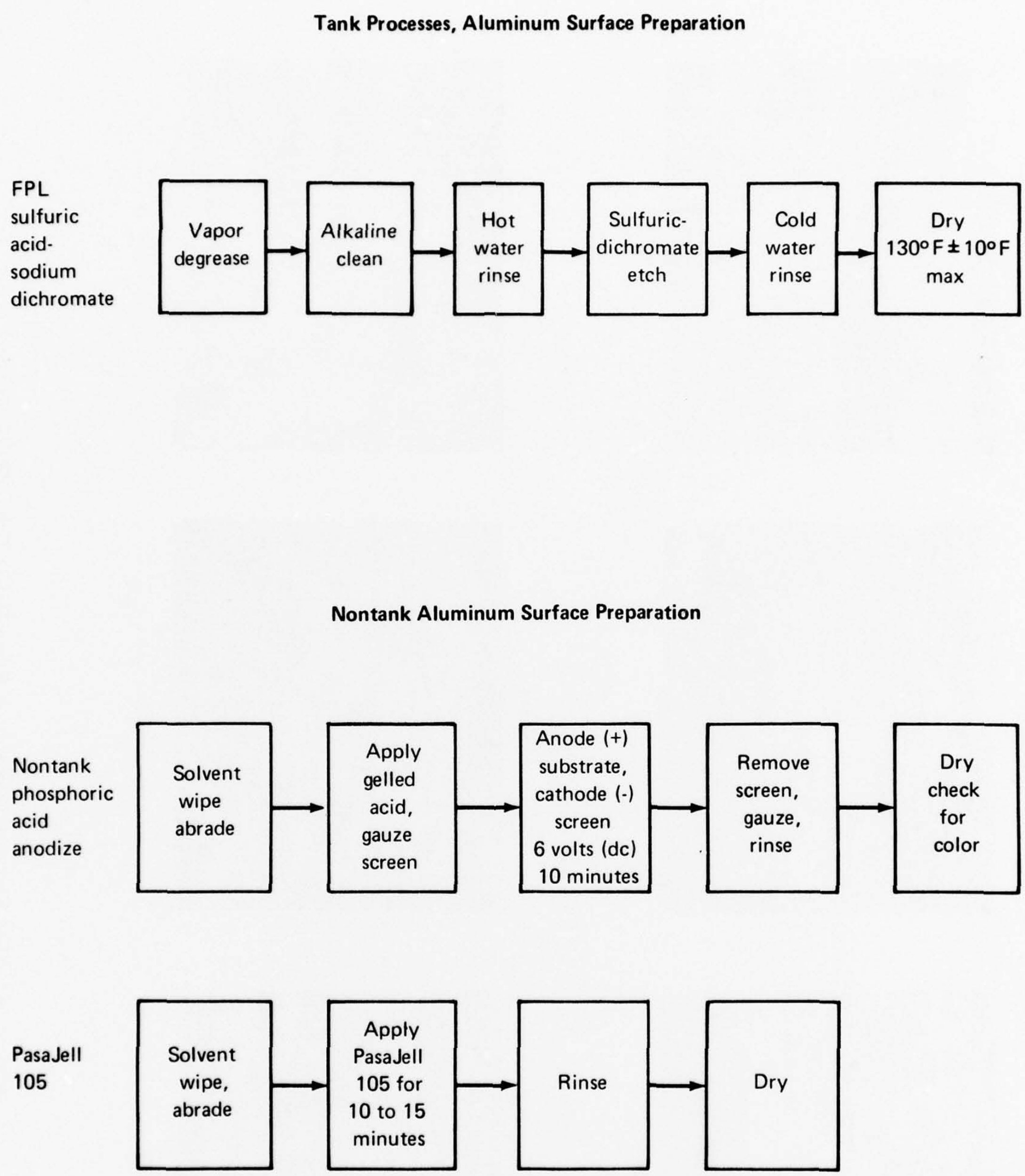


Figure 15.--Surface Preparation Processing Steps

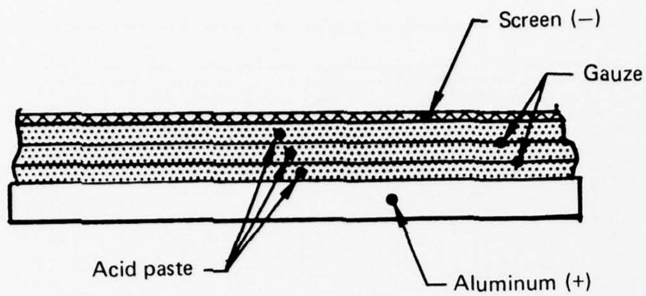


Figure 16.–Cross Section of Non-Tank Anodize Set Up-Typical

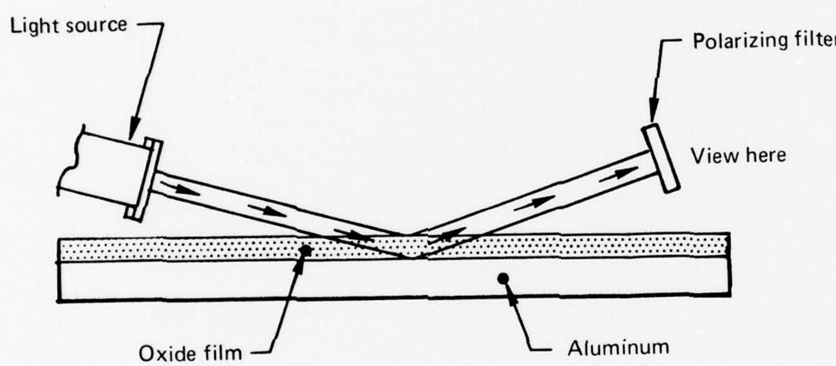


Figure 17.–Polarized Light Test-Verification of Anodic Oxide Film

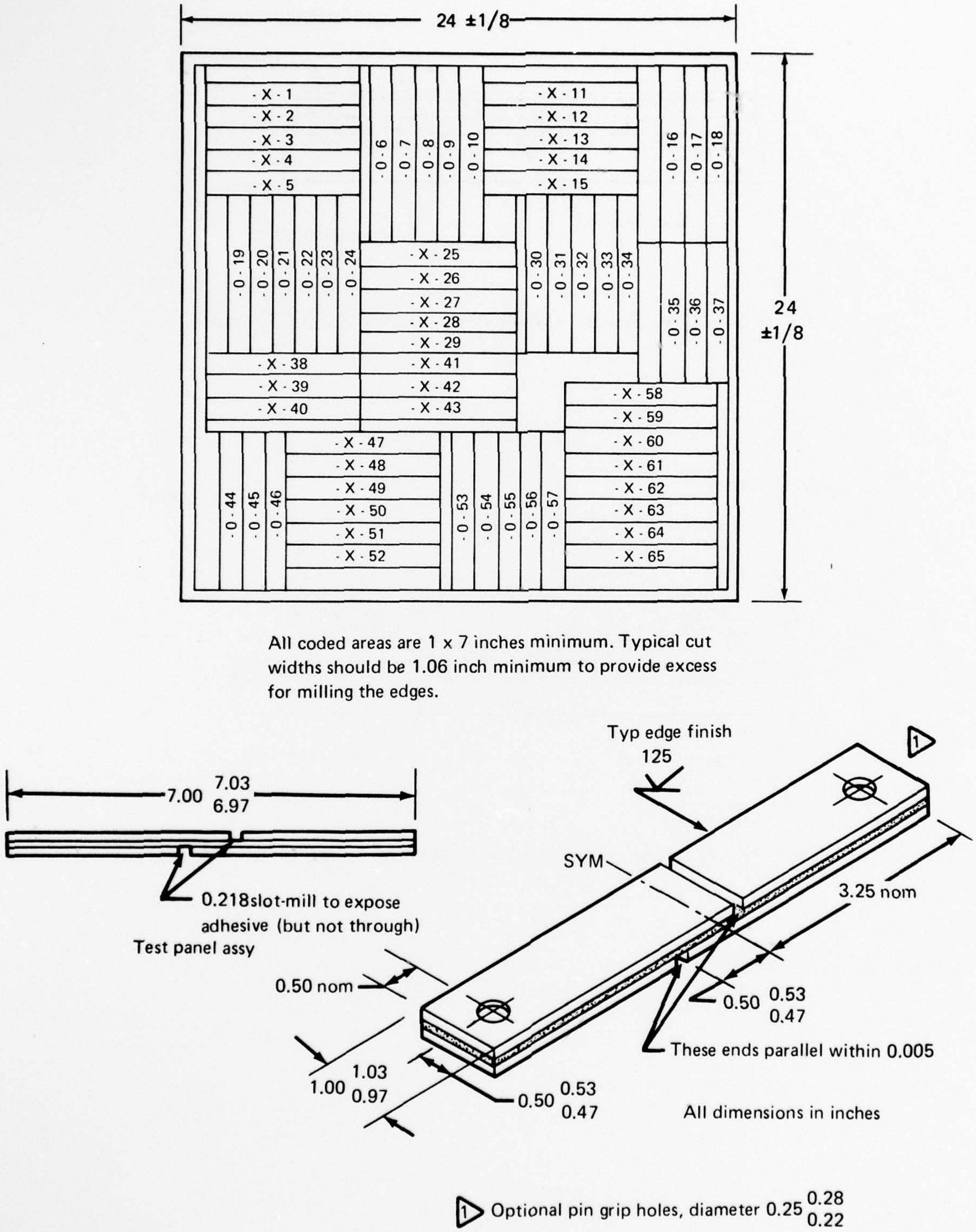
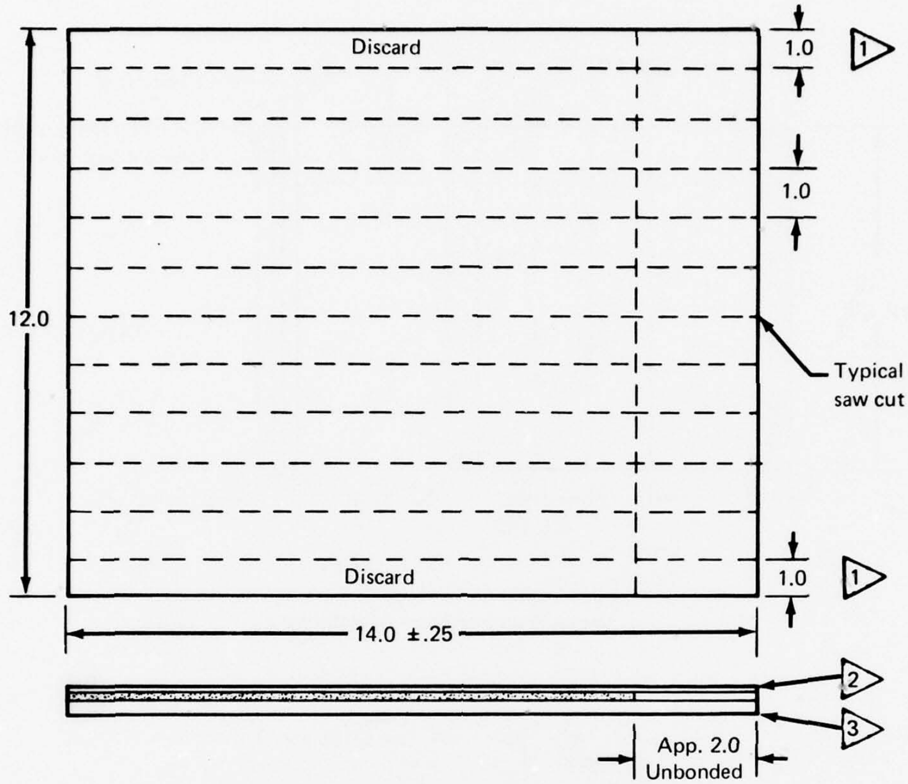


Figure 18.—Lap Shear Panel/Specimen Configuration



1 Trim discard edges shall be 0.50 inch minimum. Cut specimens 1.00 ± 0.03 inches wide.

2 0.020 inch

3 0.040 inch

Figure 19.—Metal-Metal Peel Panel/Specimen Configuration

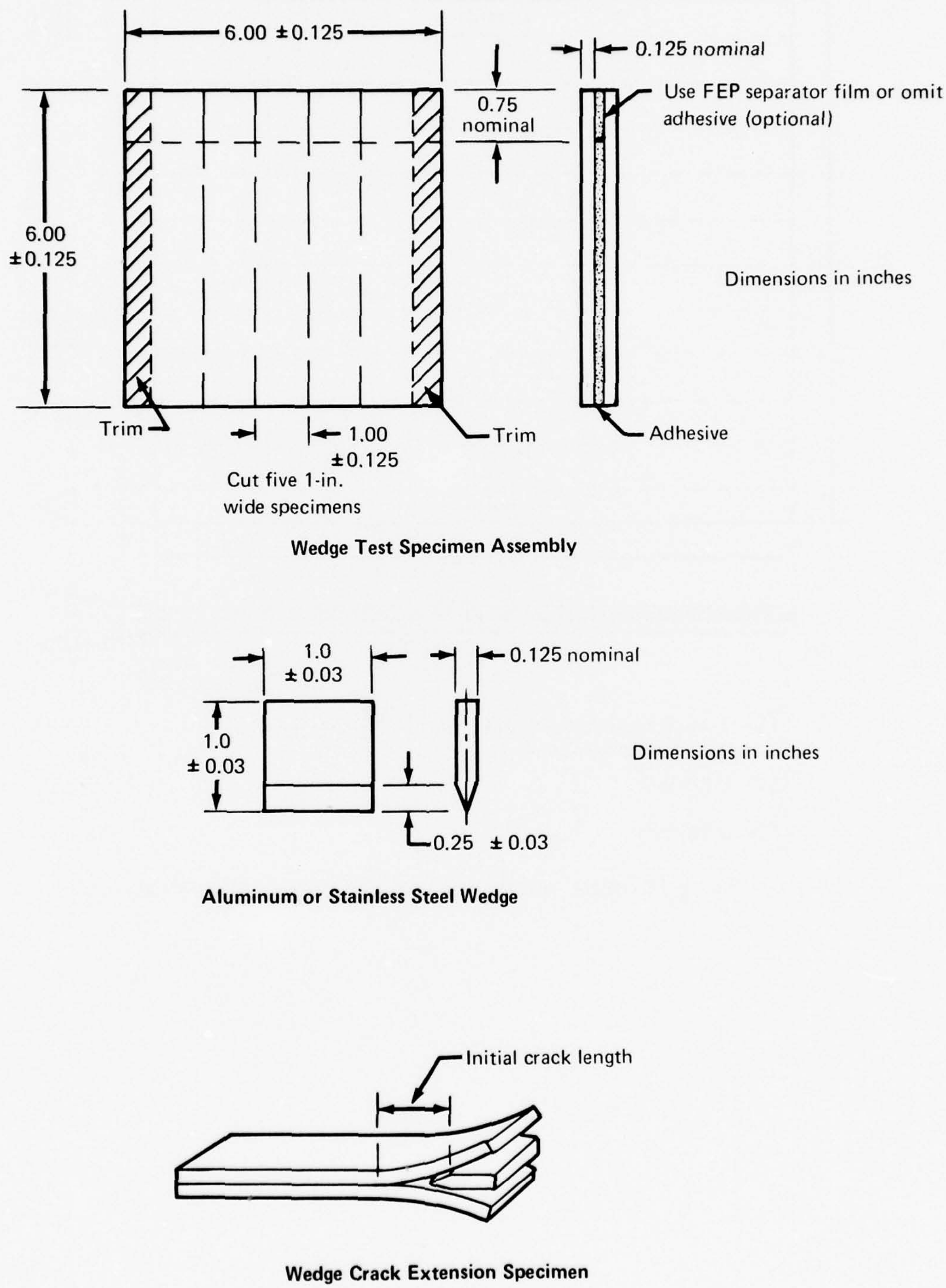


Figure 20.—Wedge Panel/Specimen Configuration

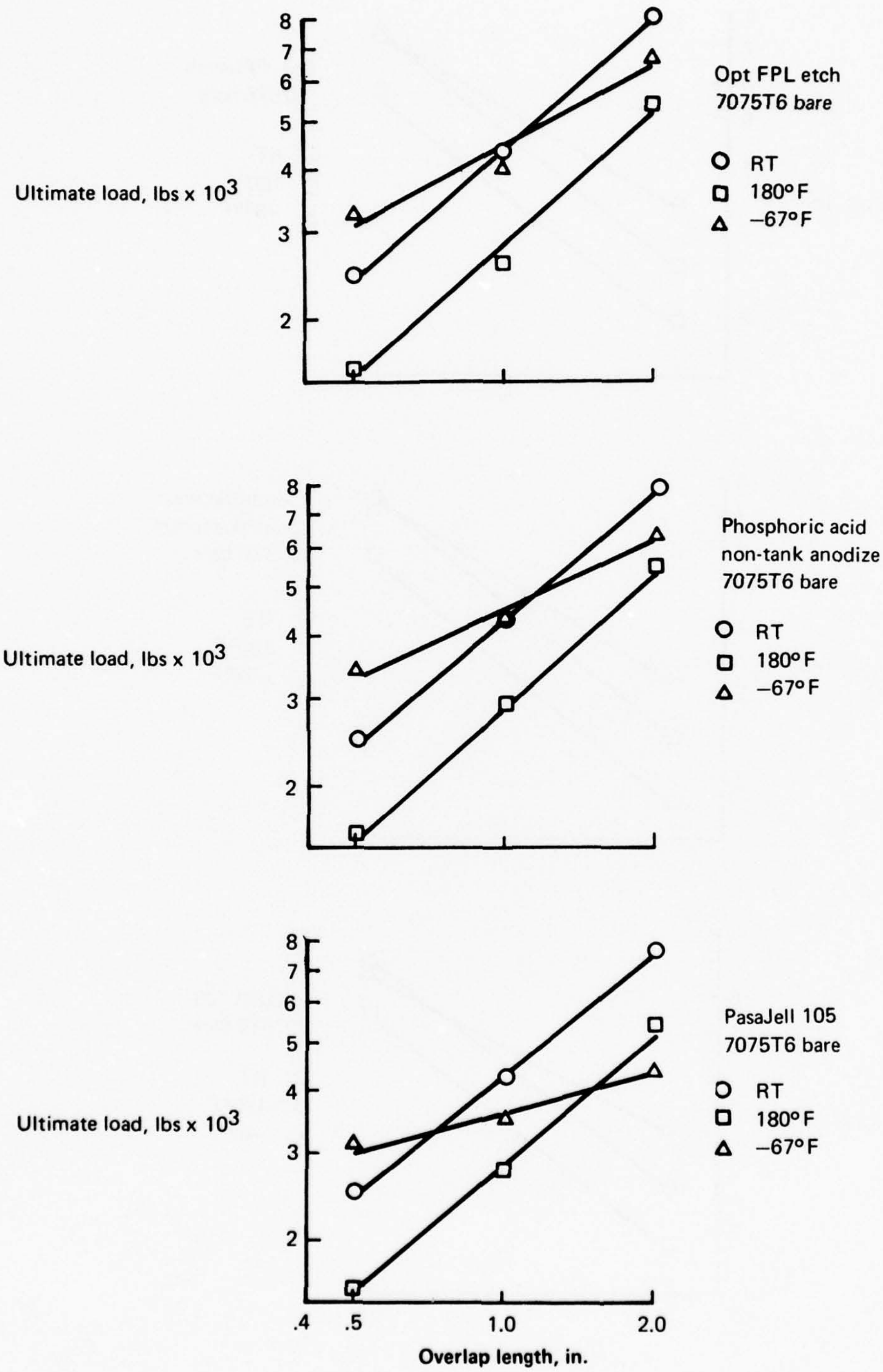


Figure 21.—L/t Lap Shear—AF 127-3/BR 127, Autoclave Bonds

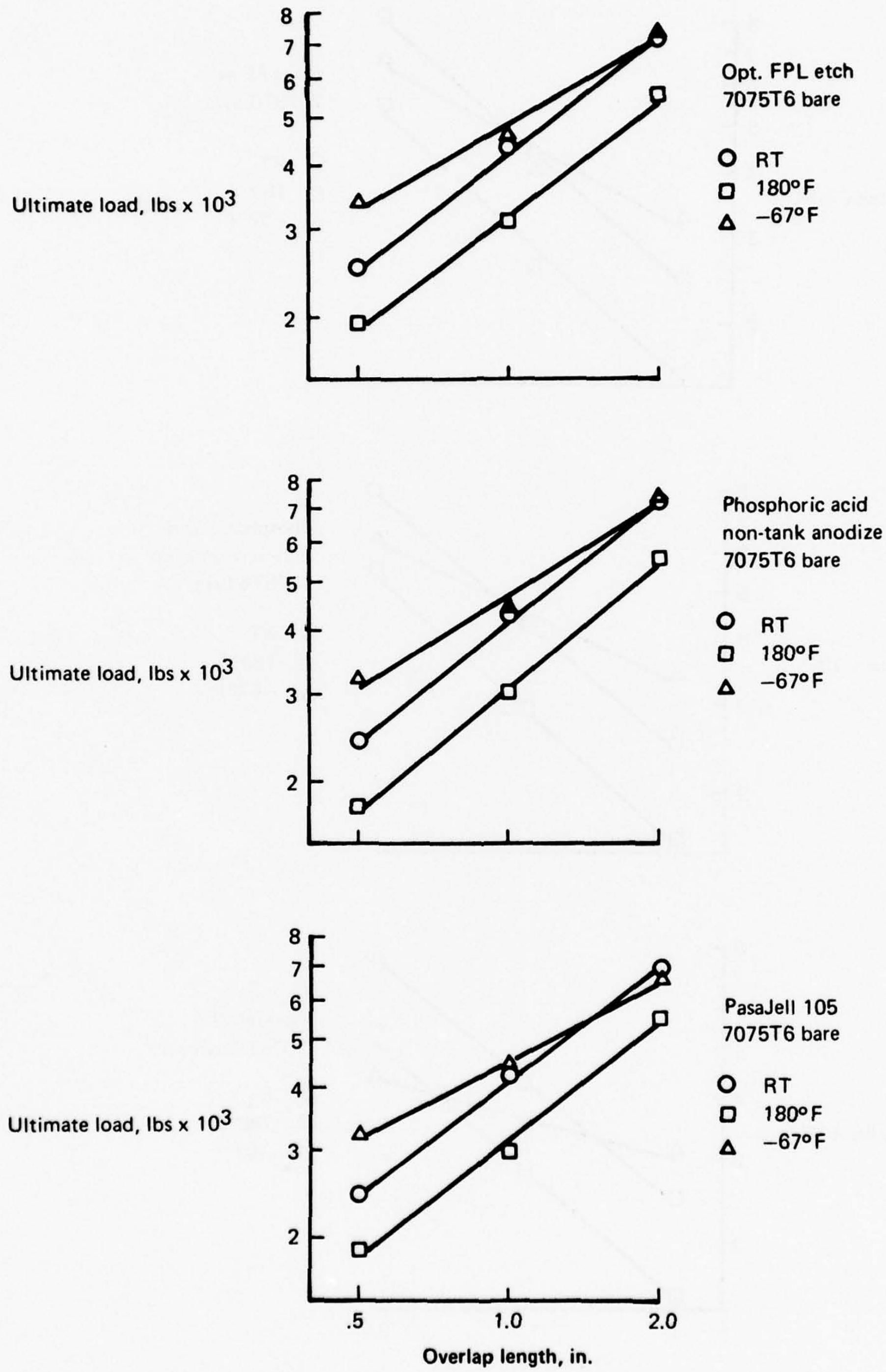


Figure 22.—L/t Lap Shear—FM 73/BR 127, Autoclave Bonds

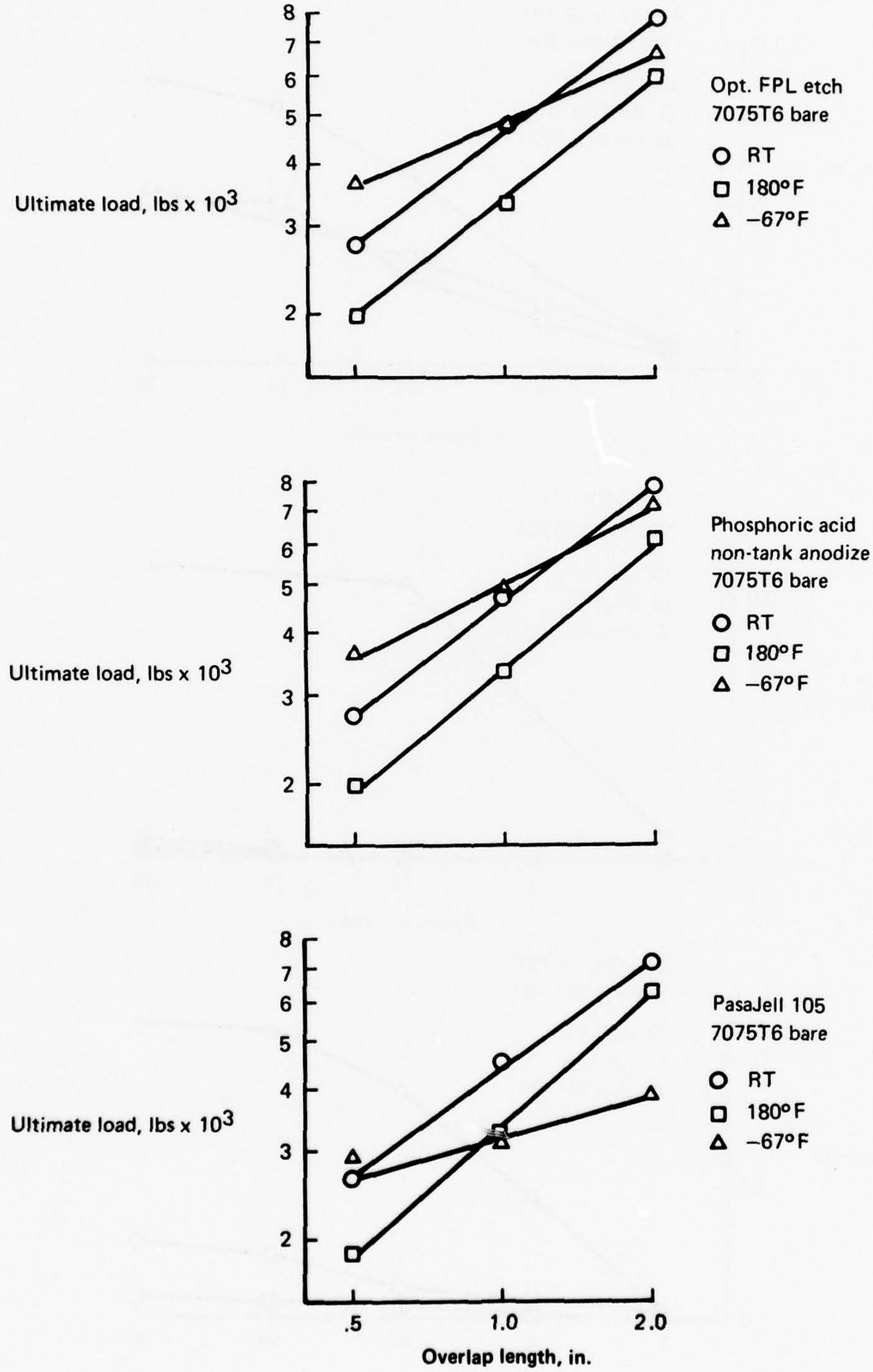


Figure 23.—L/t Lap Shear—EA 9628/BR 127, Autoclave Bonds

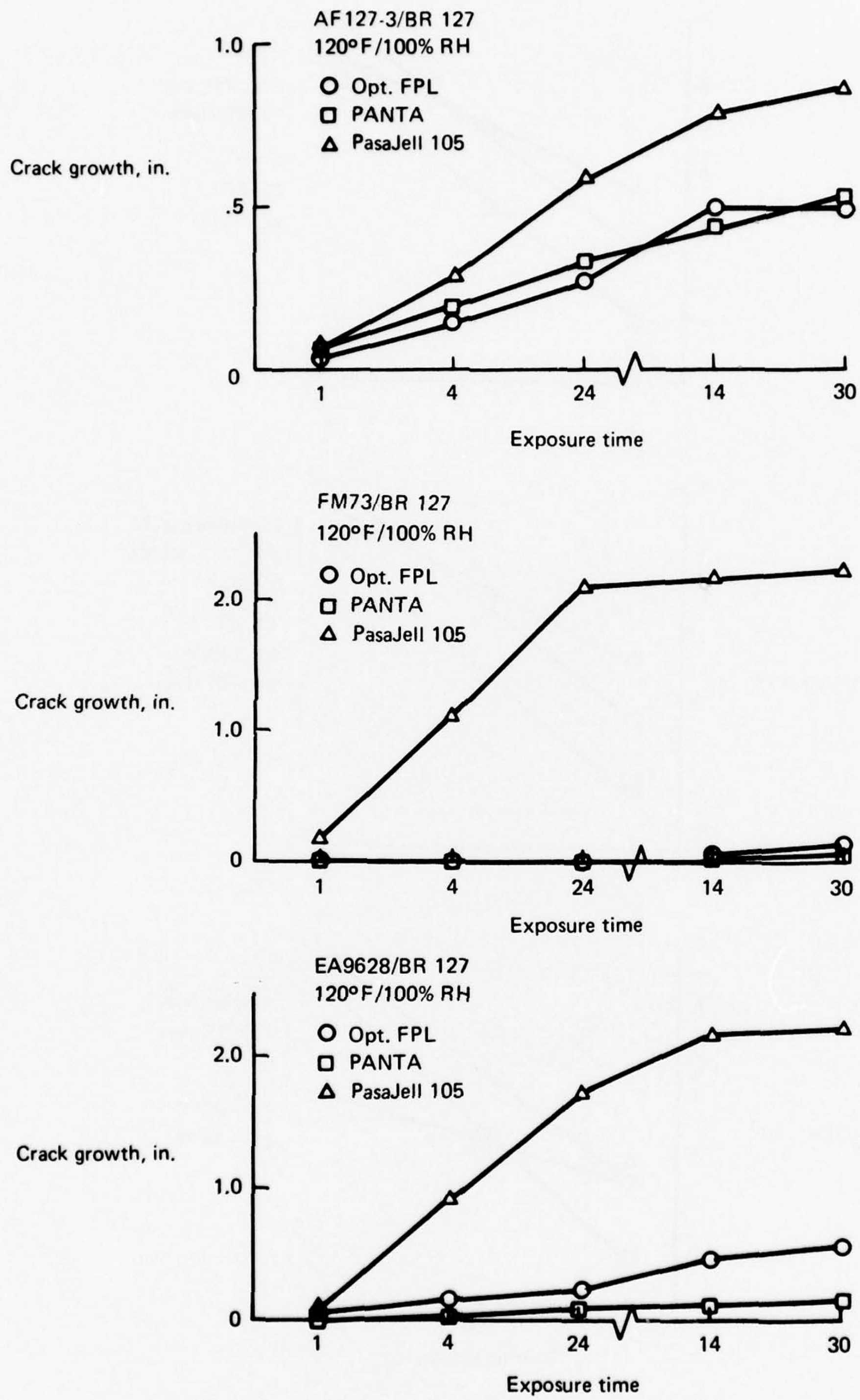


Figure 24.—Wedge Test Comparison—250°F Cure Adhesive Systems

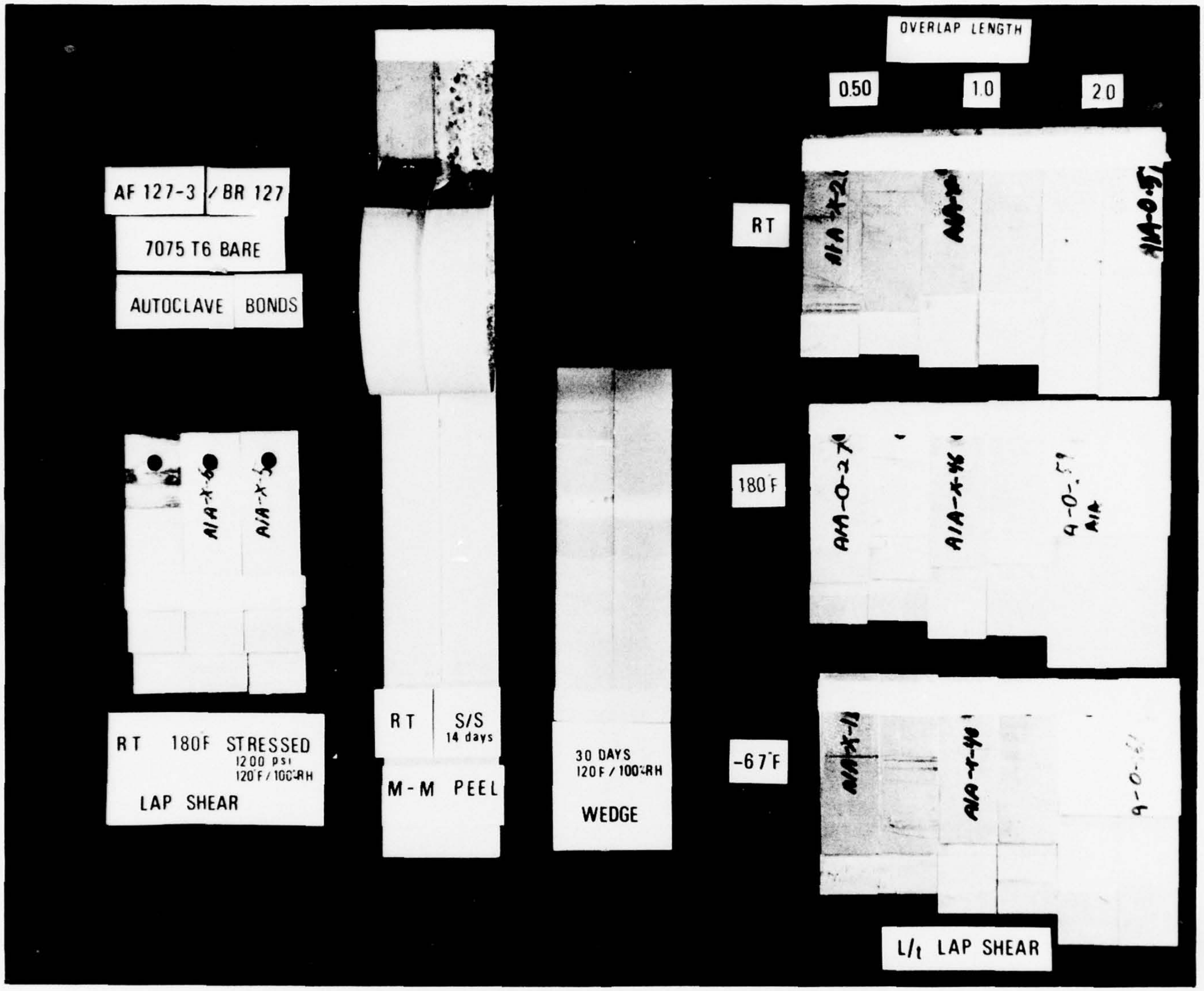


Figure 25.—Specimen Failure Surfaces—AF 127-3, Optimized FPL Etch, Autoclave Bonds

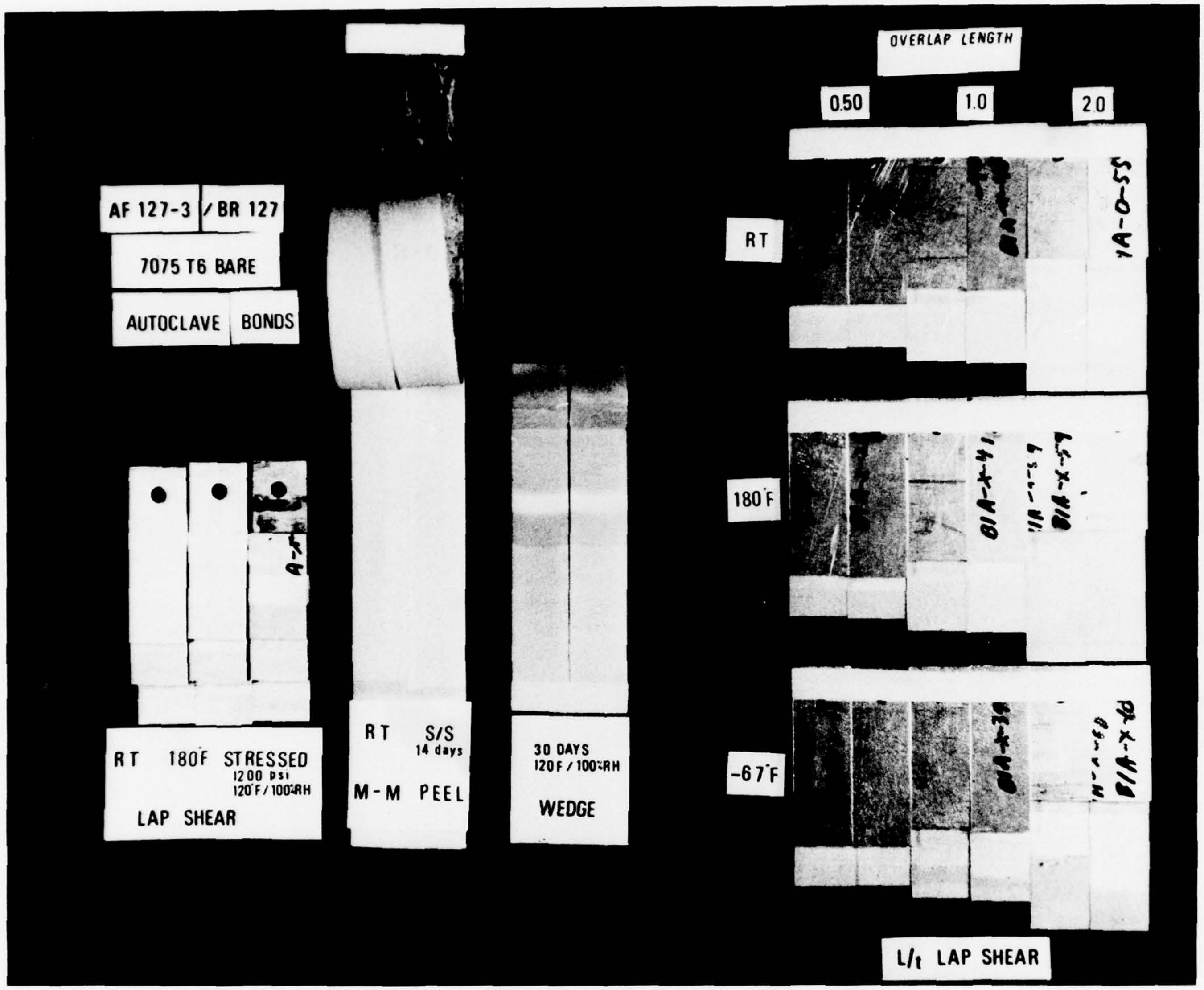


Figure 26.—Specimen Failure Surfaces—AF 127-3, Non-Tank Anodized, Autoclave Bonds

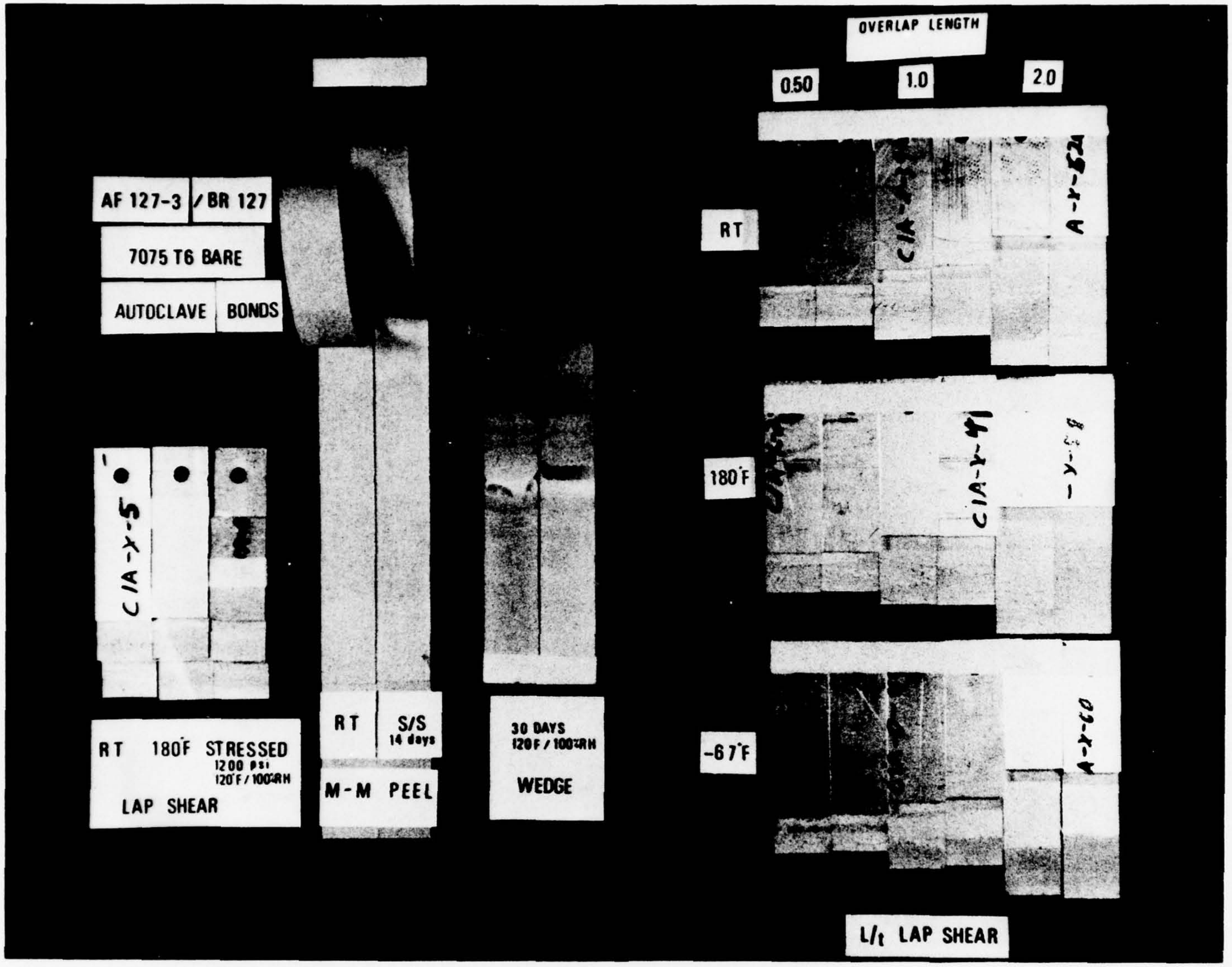


Figure 27.—Specimen Failure Surfaces—AF 127-3, PasaJell 105, Autoclave Bonds

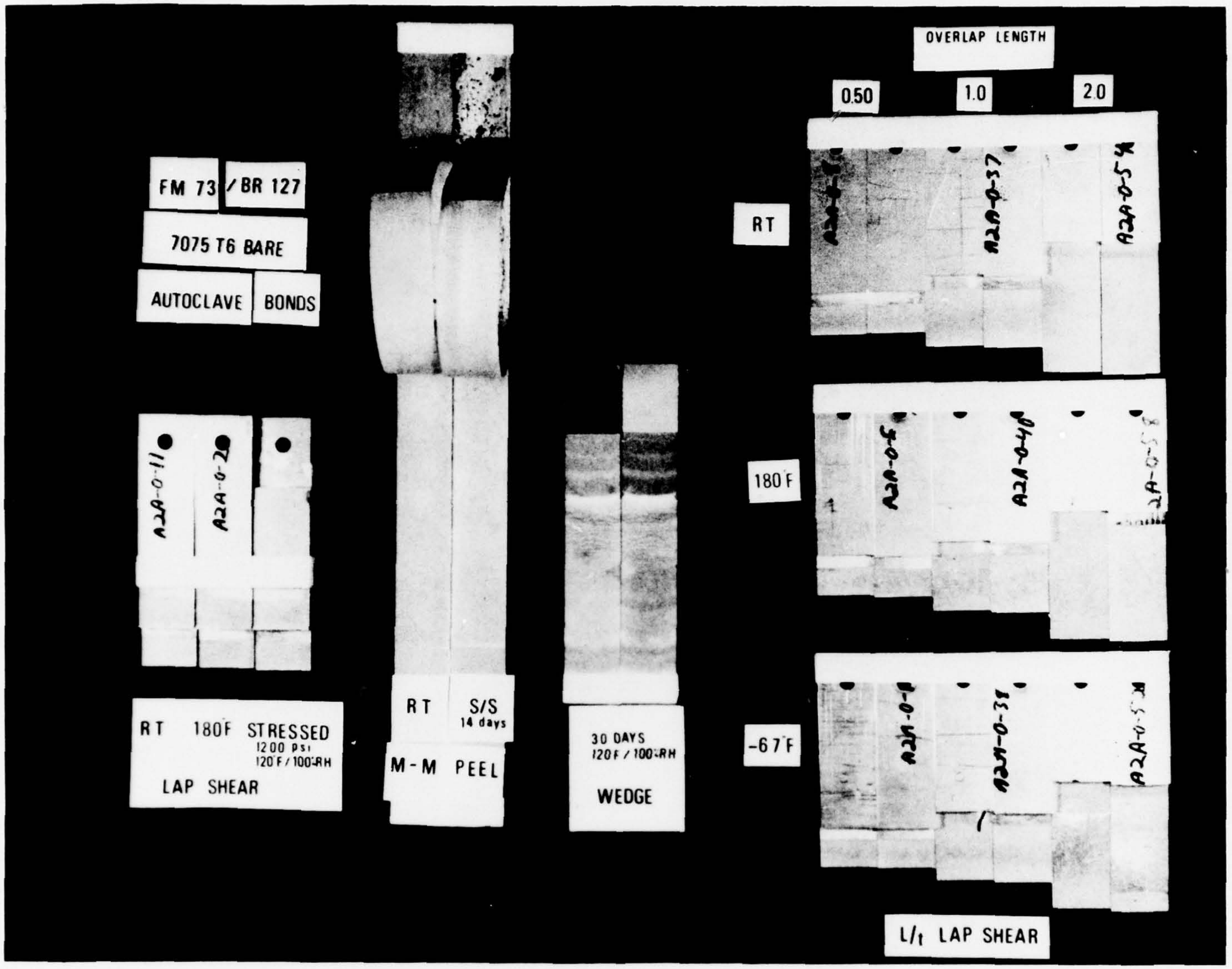


Figure 28.—Specimen Failure Surfaces—FM 73, Optimized FPL Etch, Autoclave Bonds

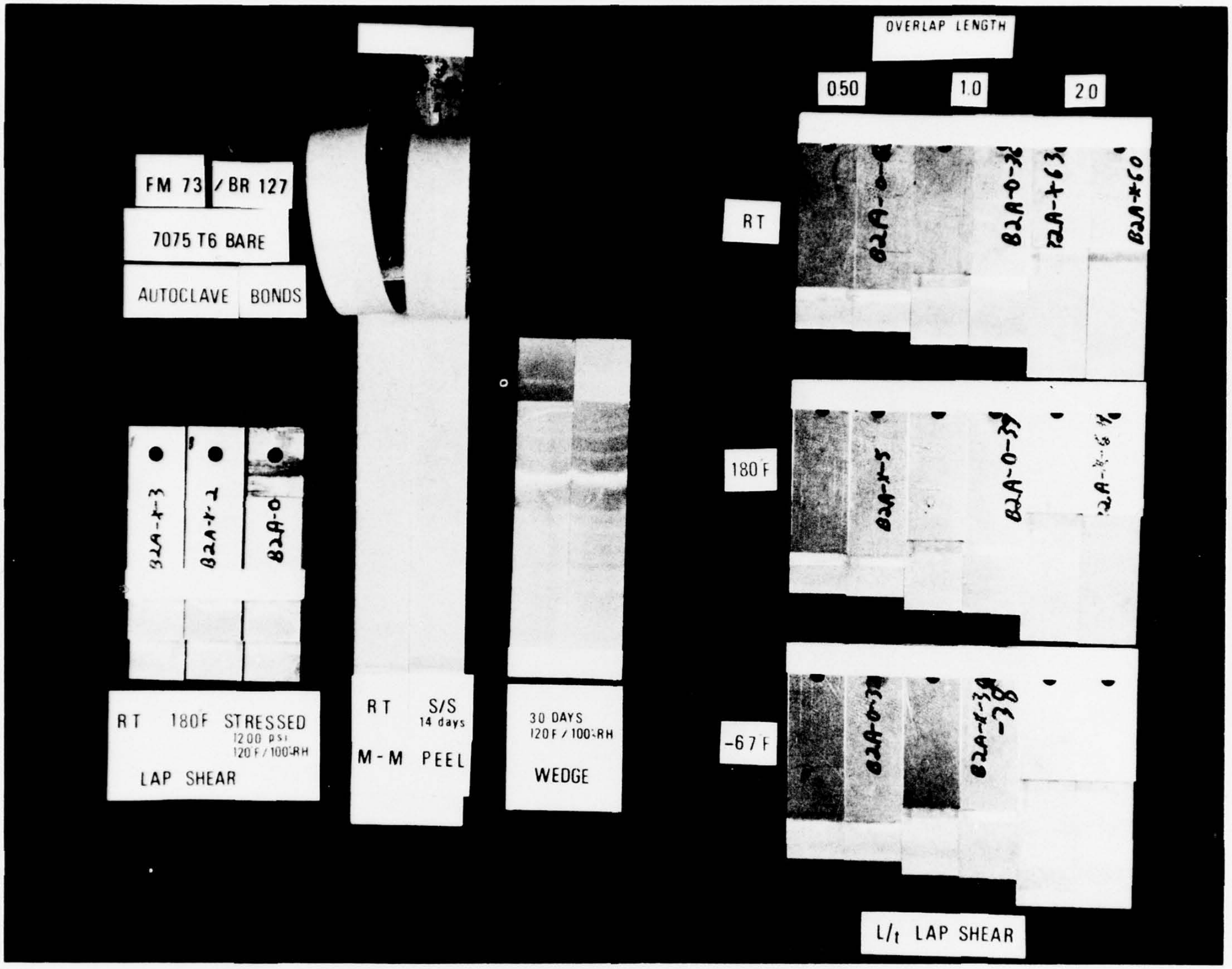


Figure 29.—Specimen Failure Surfaces—FM 73, Non-Tank Anodized, Autoclave Bonds

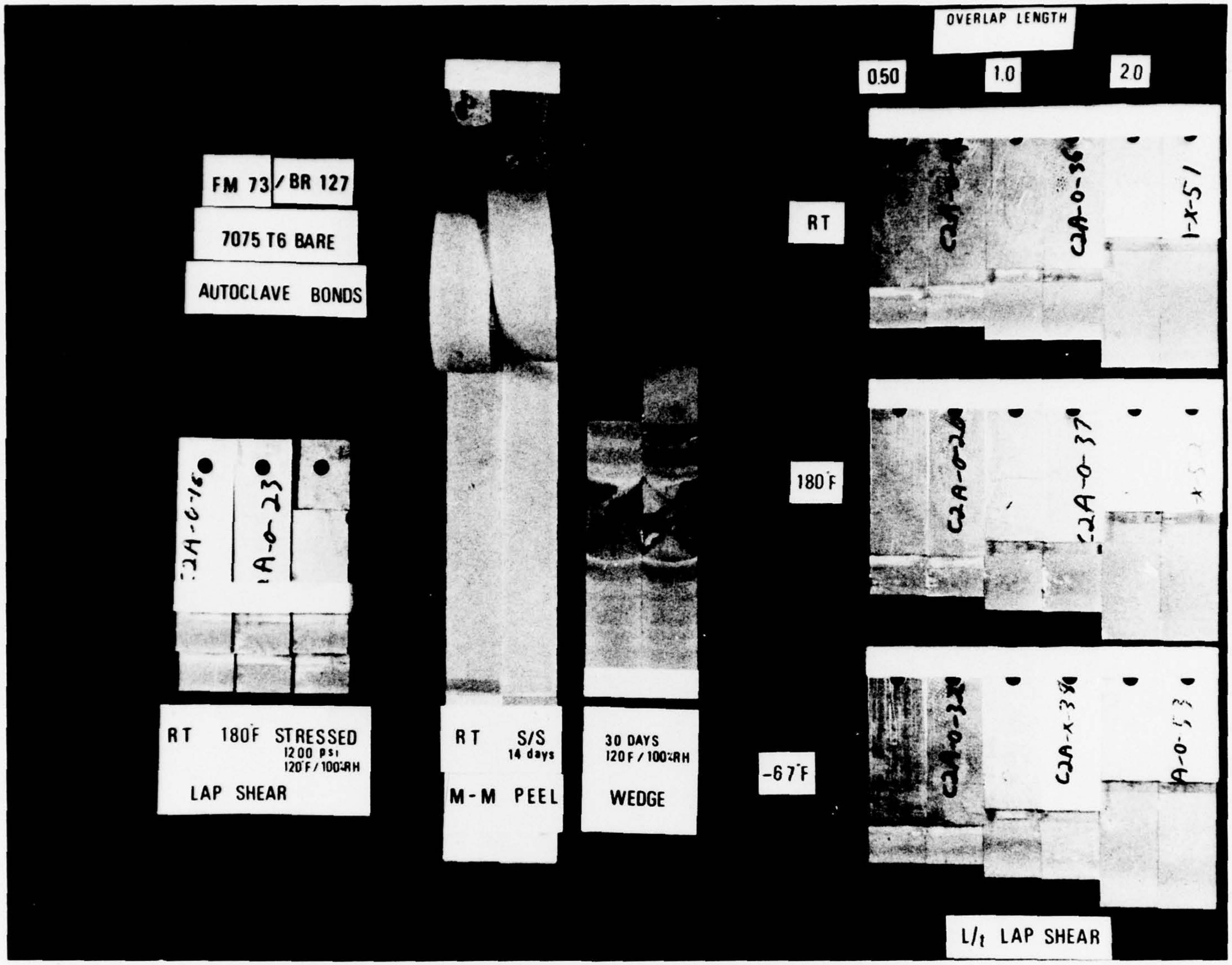


Figure 30.—Specimen Failure Surfaces—FM 73, PasaJell 105, Autoclave Bonds

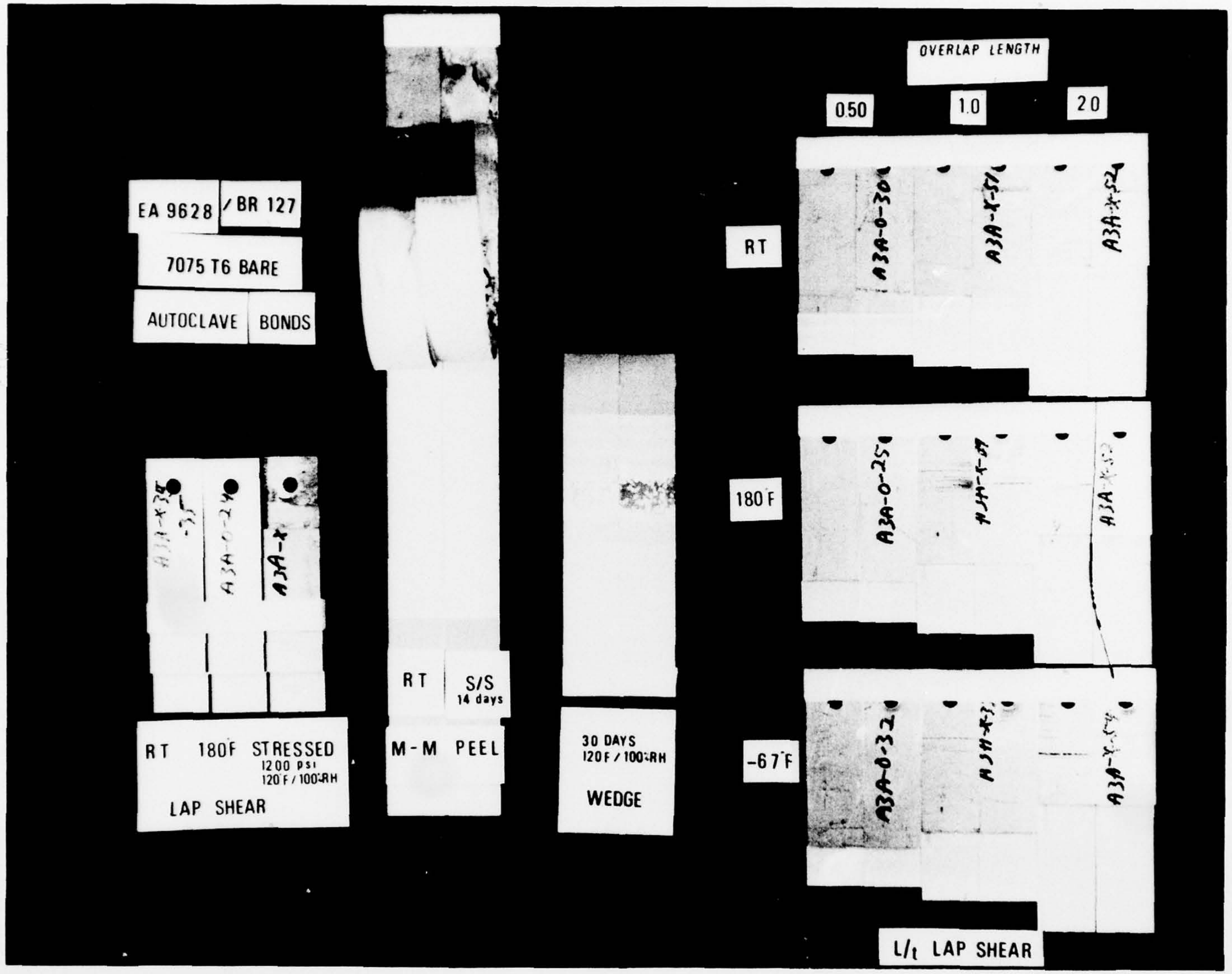


Figure 31.—Specimen Failure Surfaces—EA 9628, Optimized FPL Etch, Autoclave Bonds

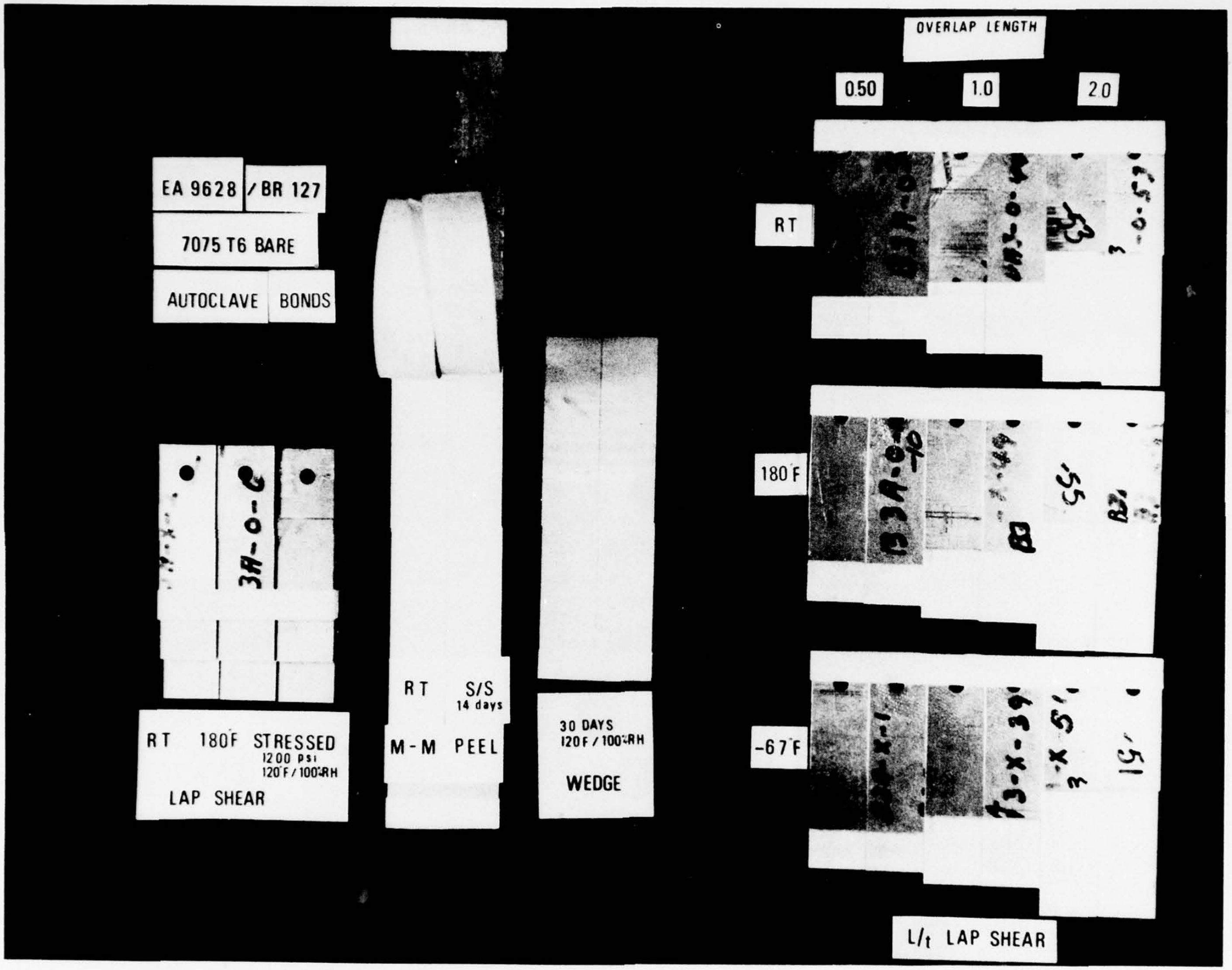


Figure 32.—Specimen Failure Surfaces—EA 9628, Non-Tank Anodized, Autoclave Bonds

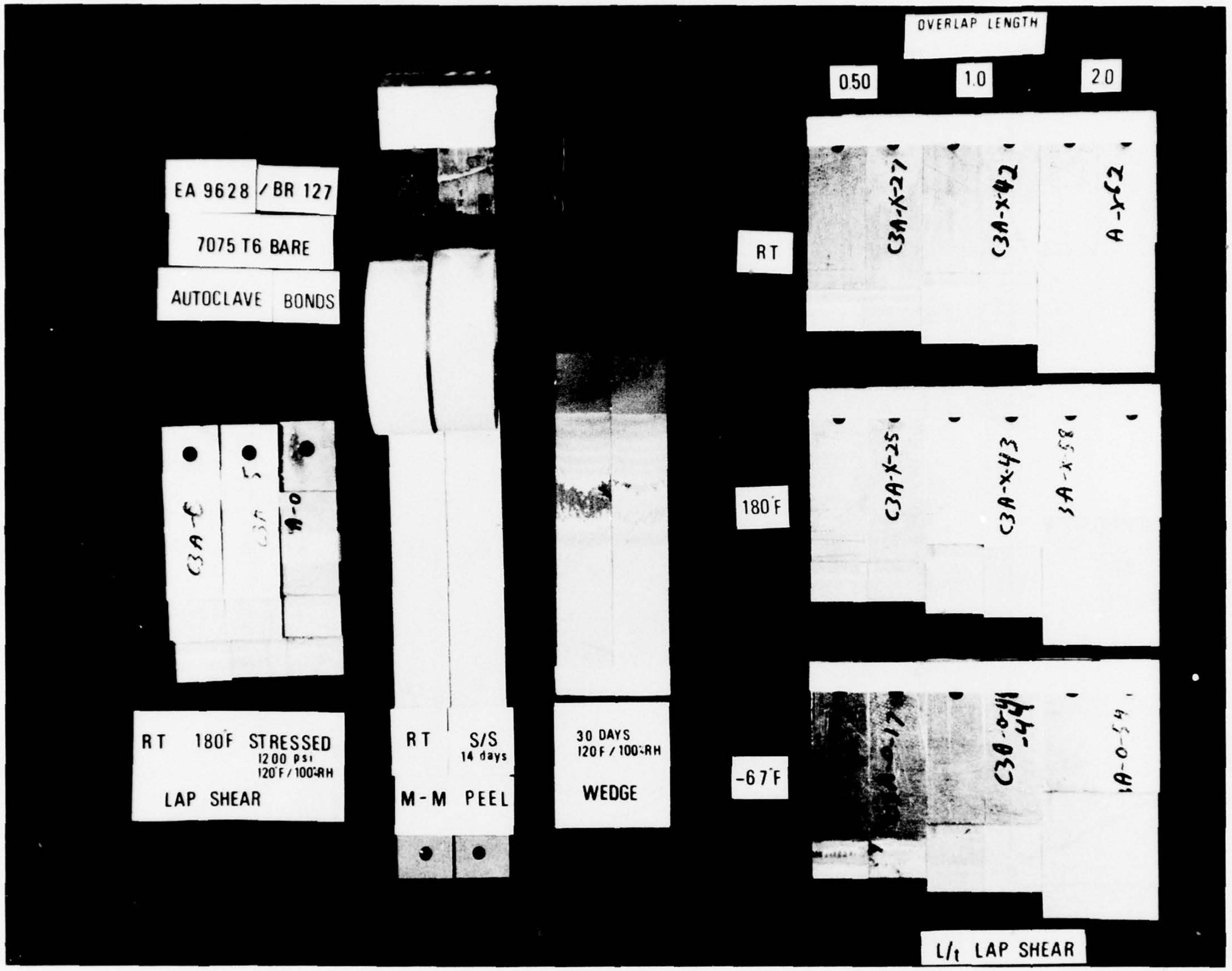


Figure 33.—Specimen Failure Surfaces—EA 9628, PasaJell 105, Autoclave Bonds

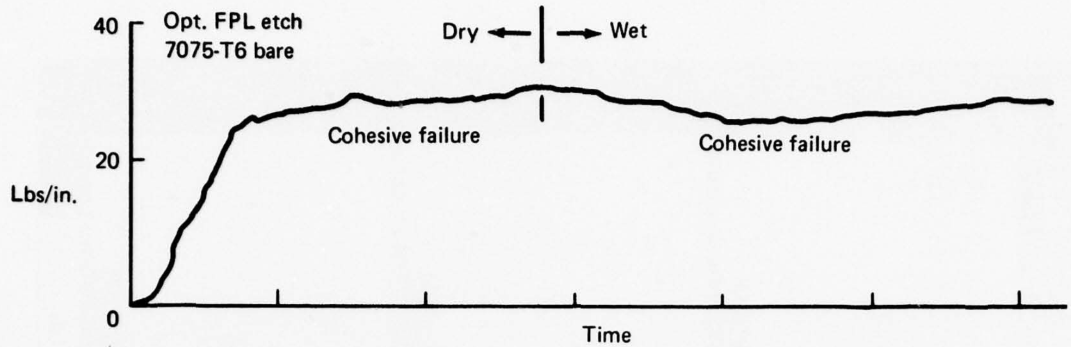


Figure 34.—Dry/Wet Peel—FM 73, Optimized FPL Etch

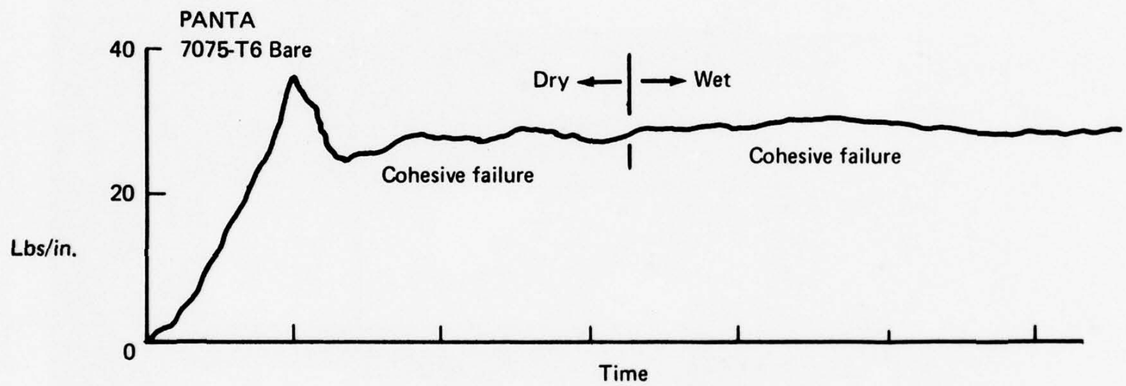


Figure 35.—Dry/Wet Peel—FM 73, Non-Tank Anodized

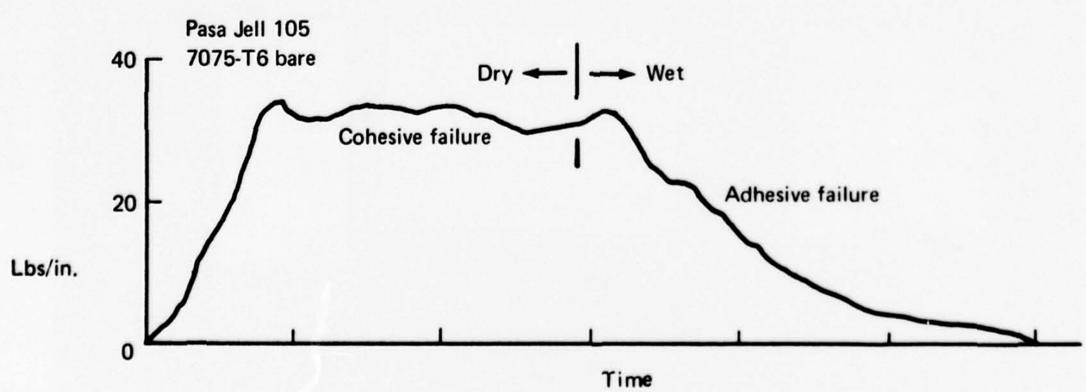


Figure 36.—Dry/Wet Peel—FM 73, PasaJell 105

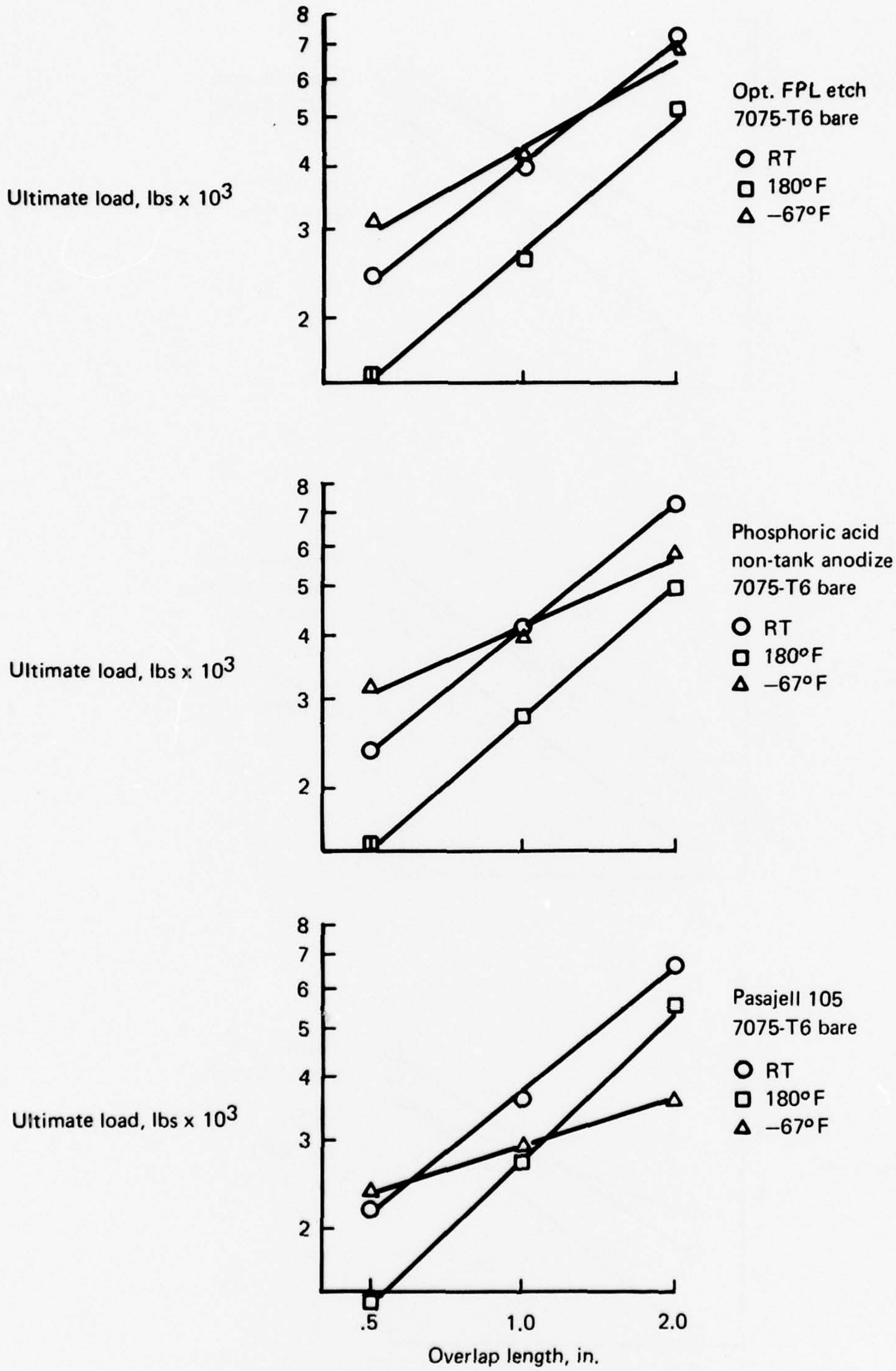


Figure 37.—L/t Lap Shear—AF 127-3/BR 127 Vacuum Bag Bonds

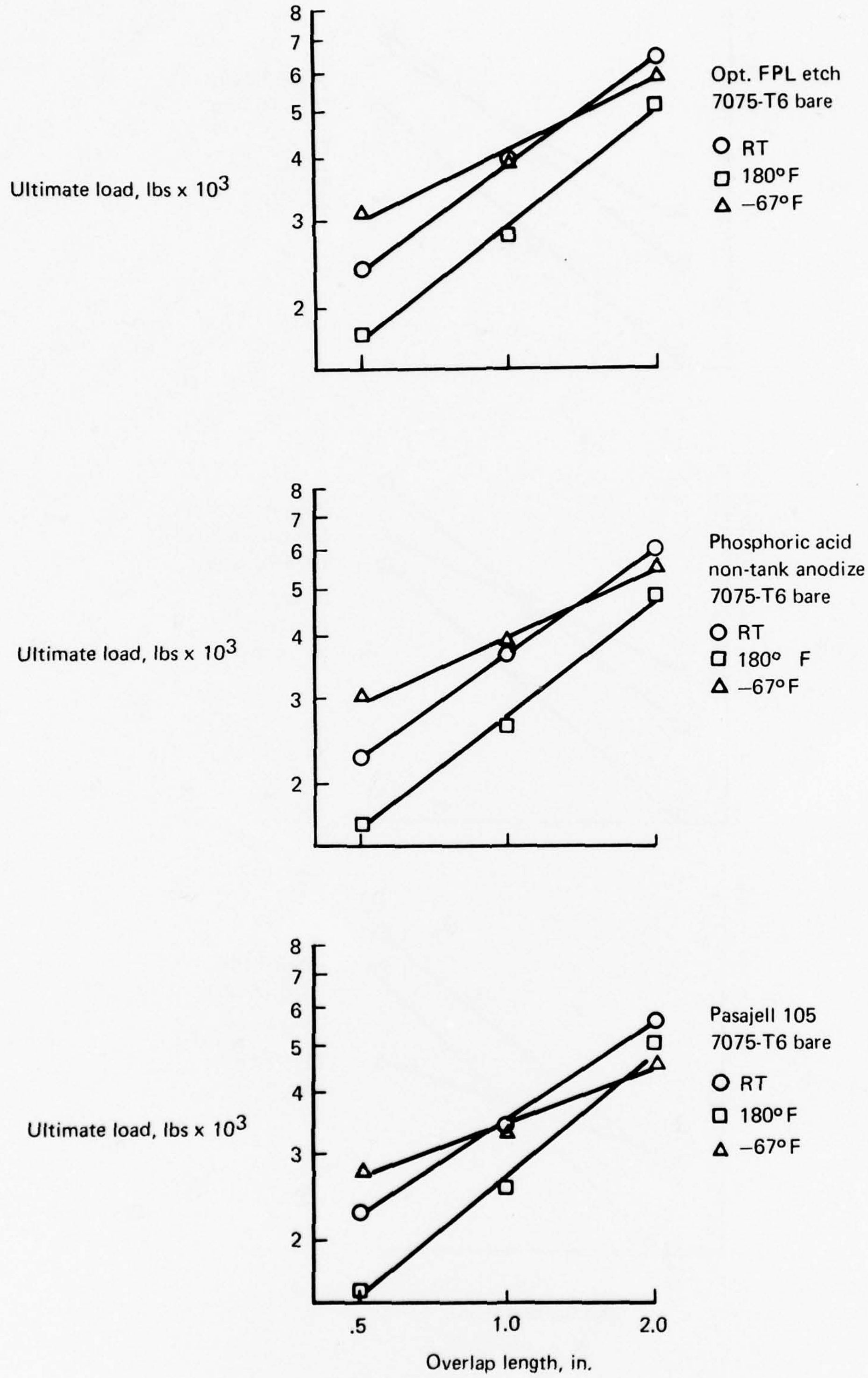


Figure 38.–L/t Lap Shear–FM 73/BR 127, Vacuum Bag Bonds

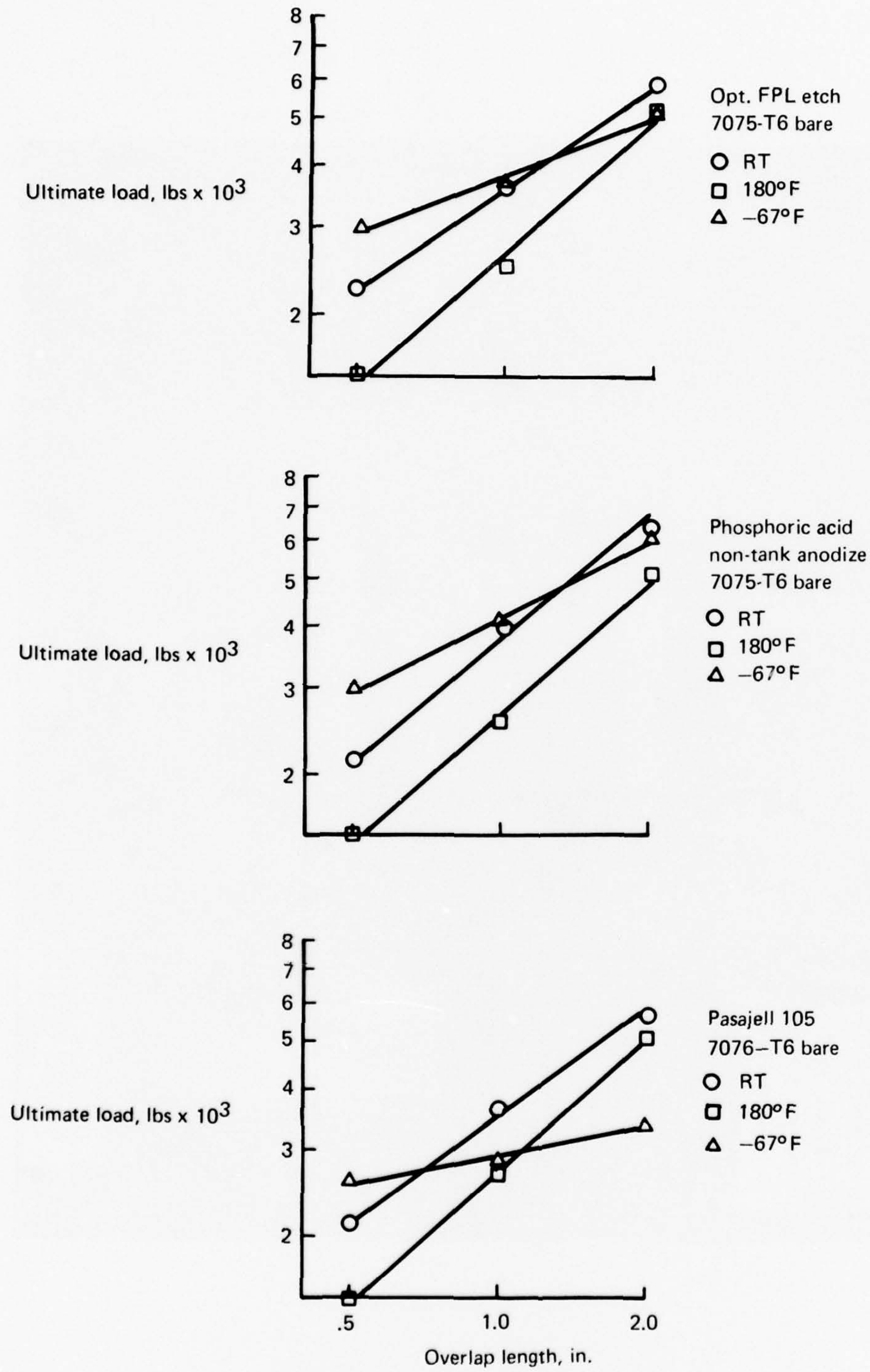


Figure 39.—L/t Lap Shear—EA 9628/BR 127, Vacuum Bag Bonds

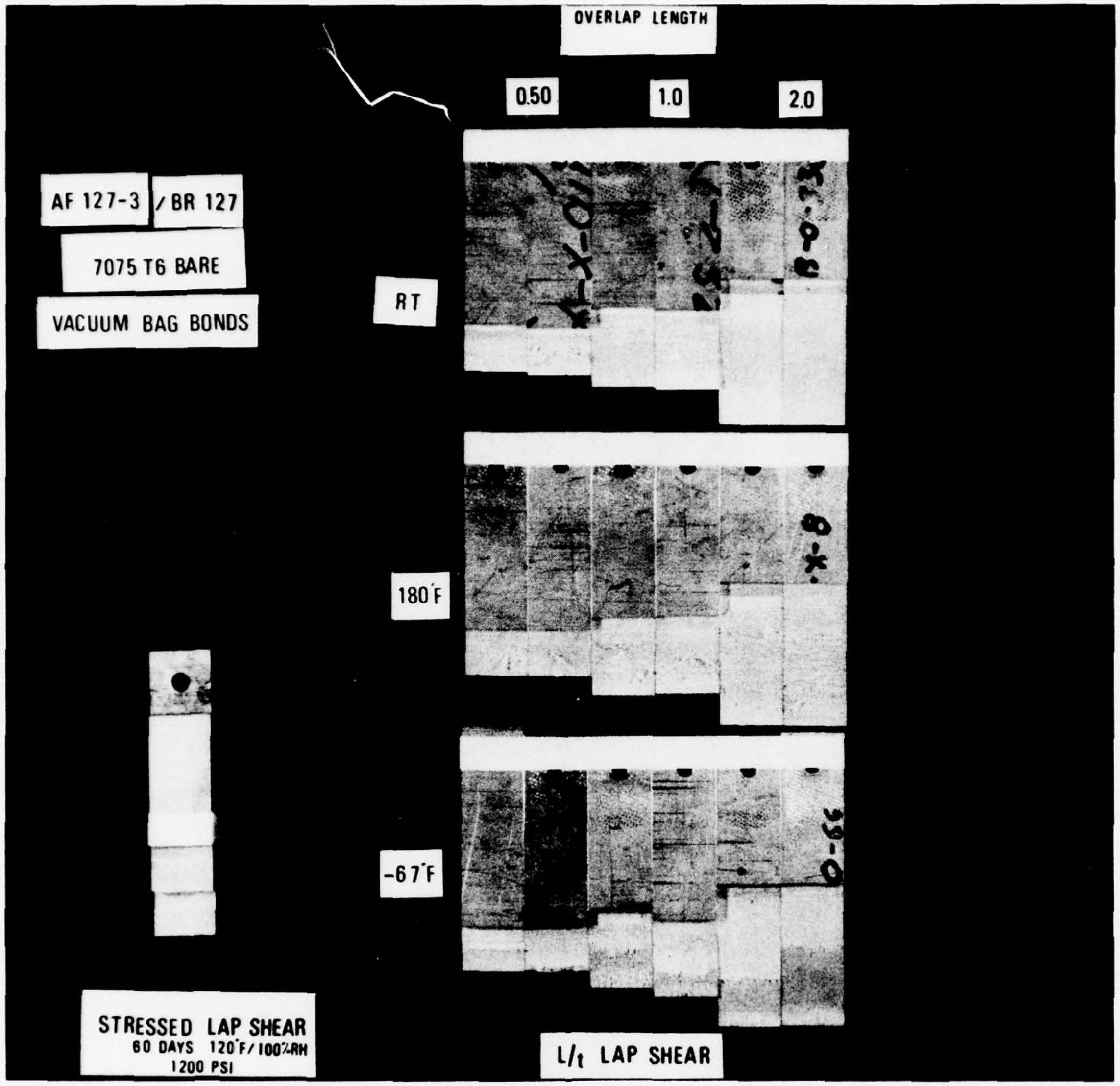


Figure 40.—Specimen Failure Surfaces—AF 127-3, Optimized FPL Etch, Vacuum Bag Bonds

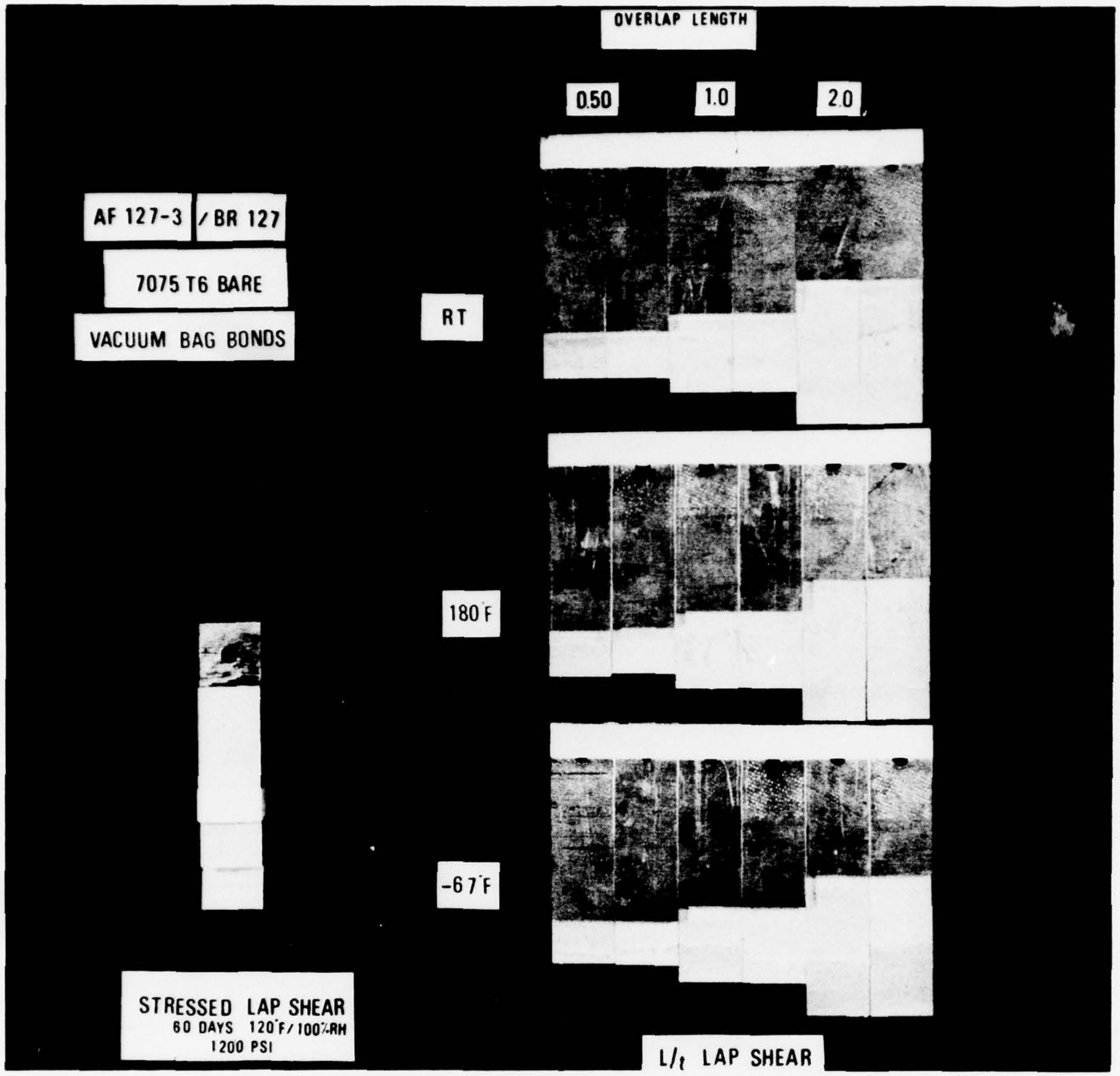


Figure 41.—Specimen Failure Surfaces—AF 127-3, Non-Tank Anodized, Vacuum Bag Bonds

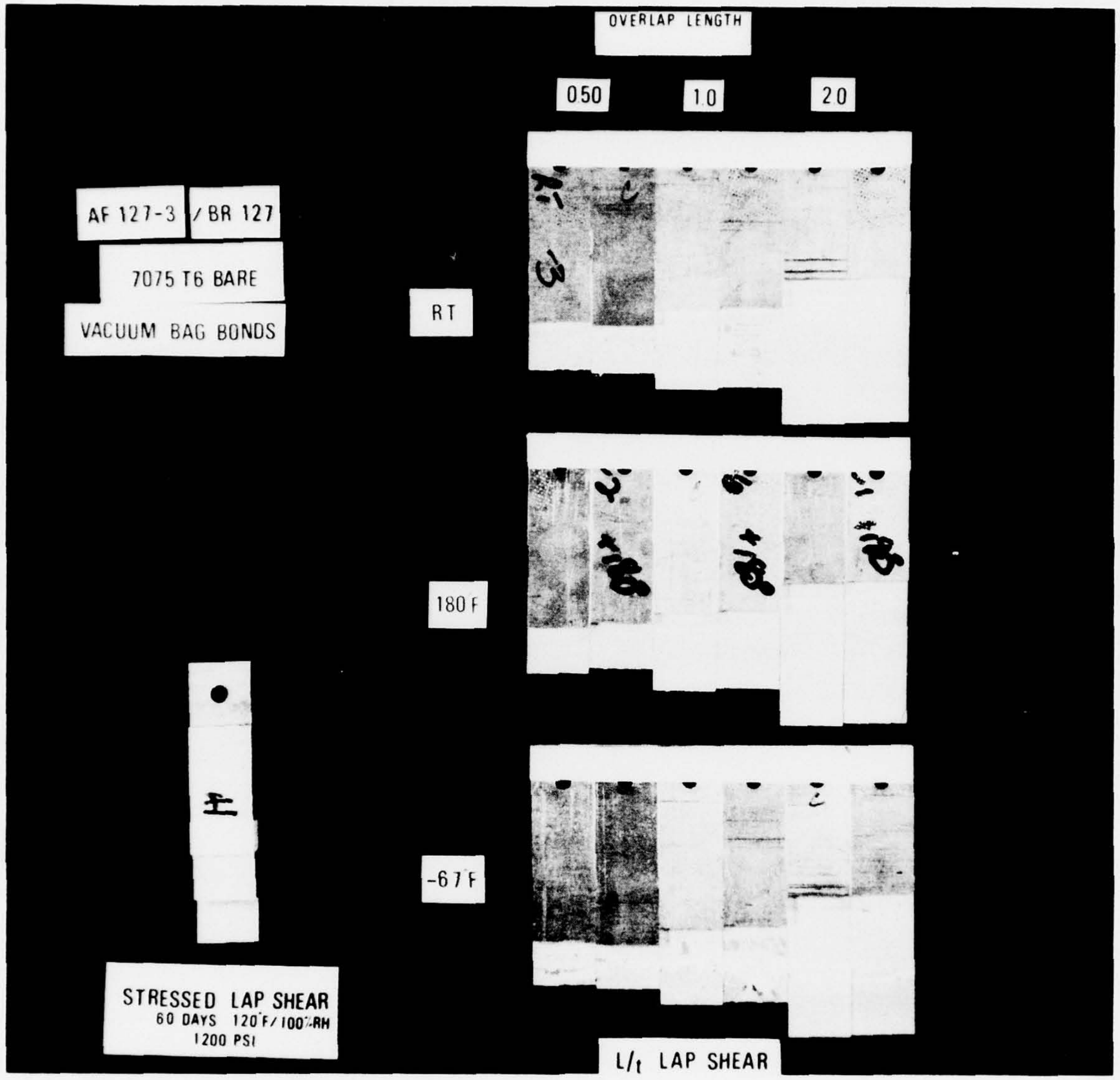


Figure 42.—Specimen Failure Surfaces—AF 127-3, PasaJell 105, Vacuum Bag Bonds

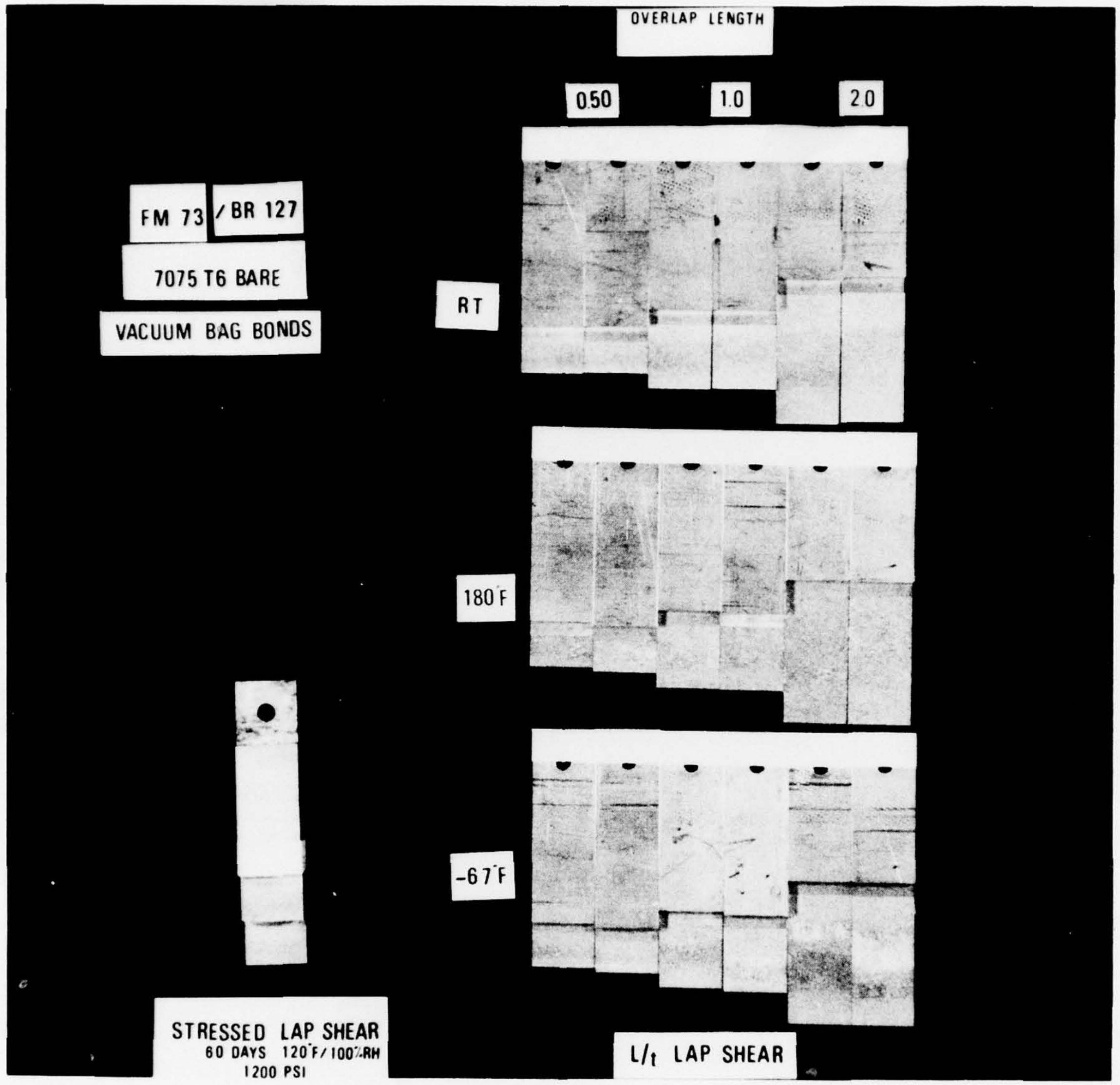


Figure 43.– Specimen Failure Surfaces–FM 73, Optimized FPL Etch, Vacuum Bag Bonds

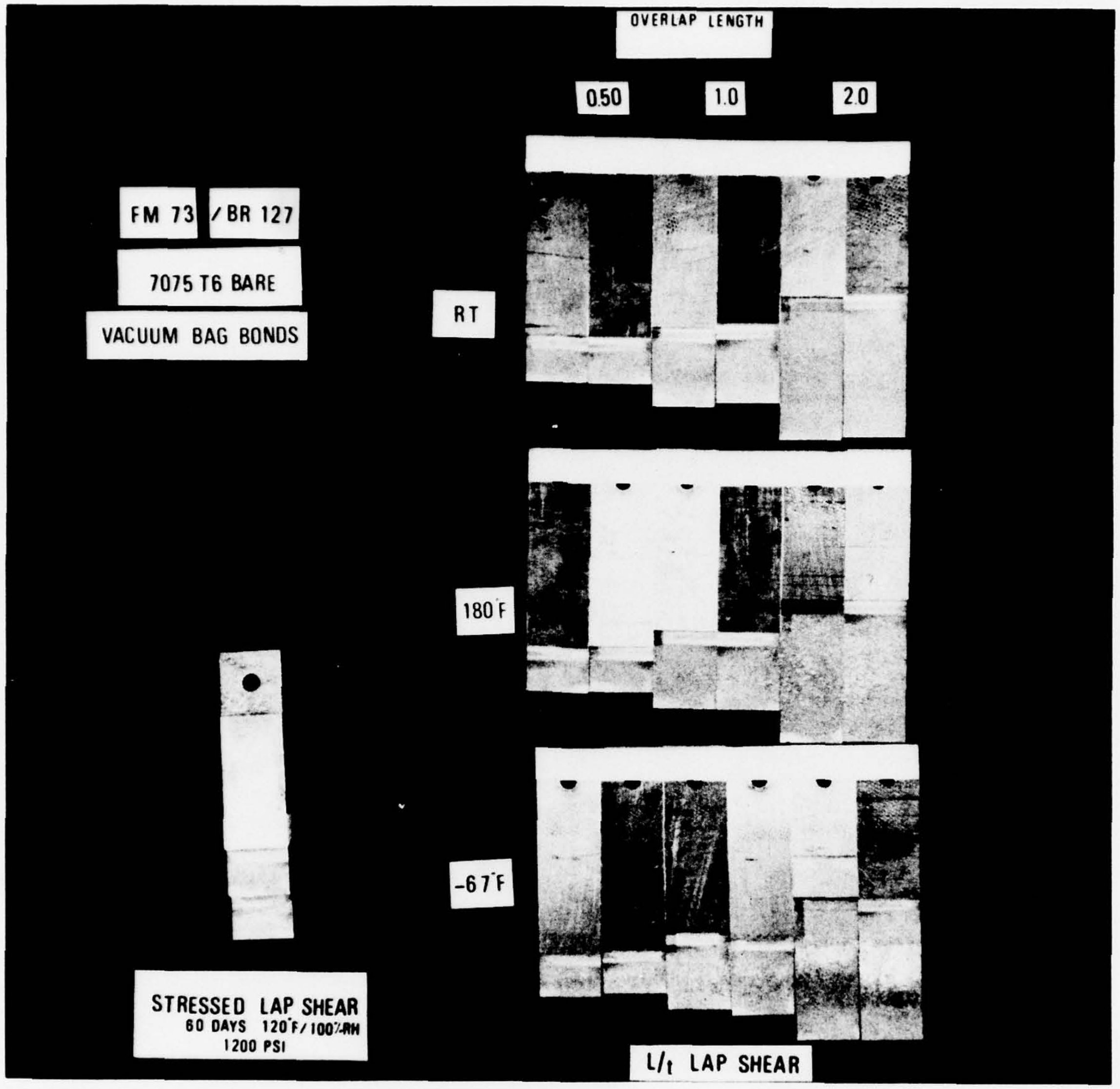


Figure 44.—Specimen Failure Surfaces—FM 73, Non-Tank Anodized, Vacuum Bag Bonds

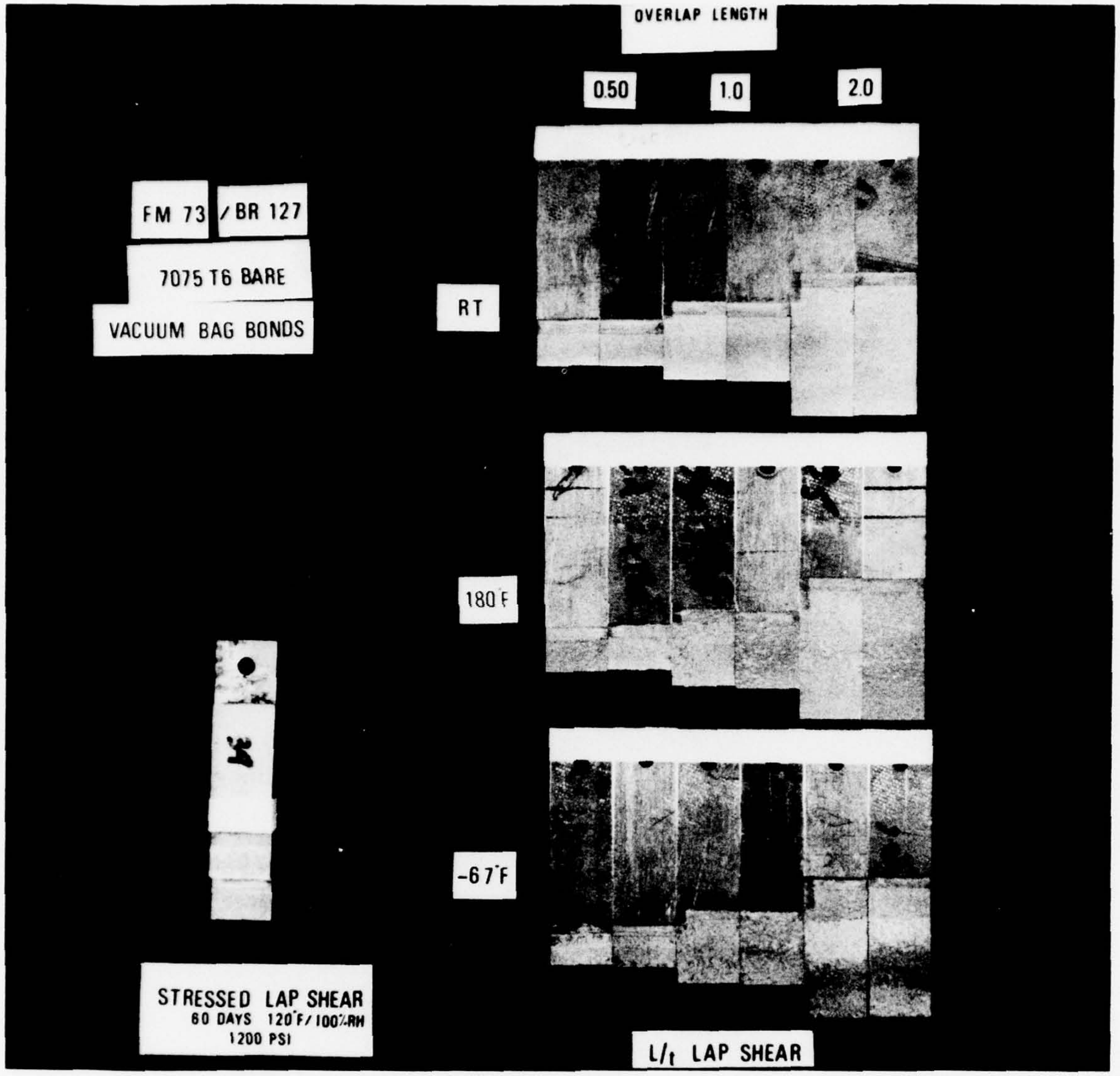


Figure 45.—Specimen Failure Surfaces—FM 73, PasaJell 105, Vacuum Bag Bonds

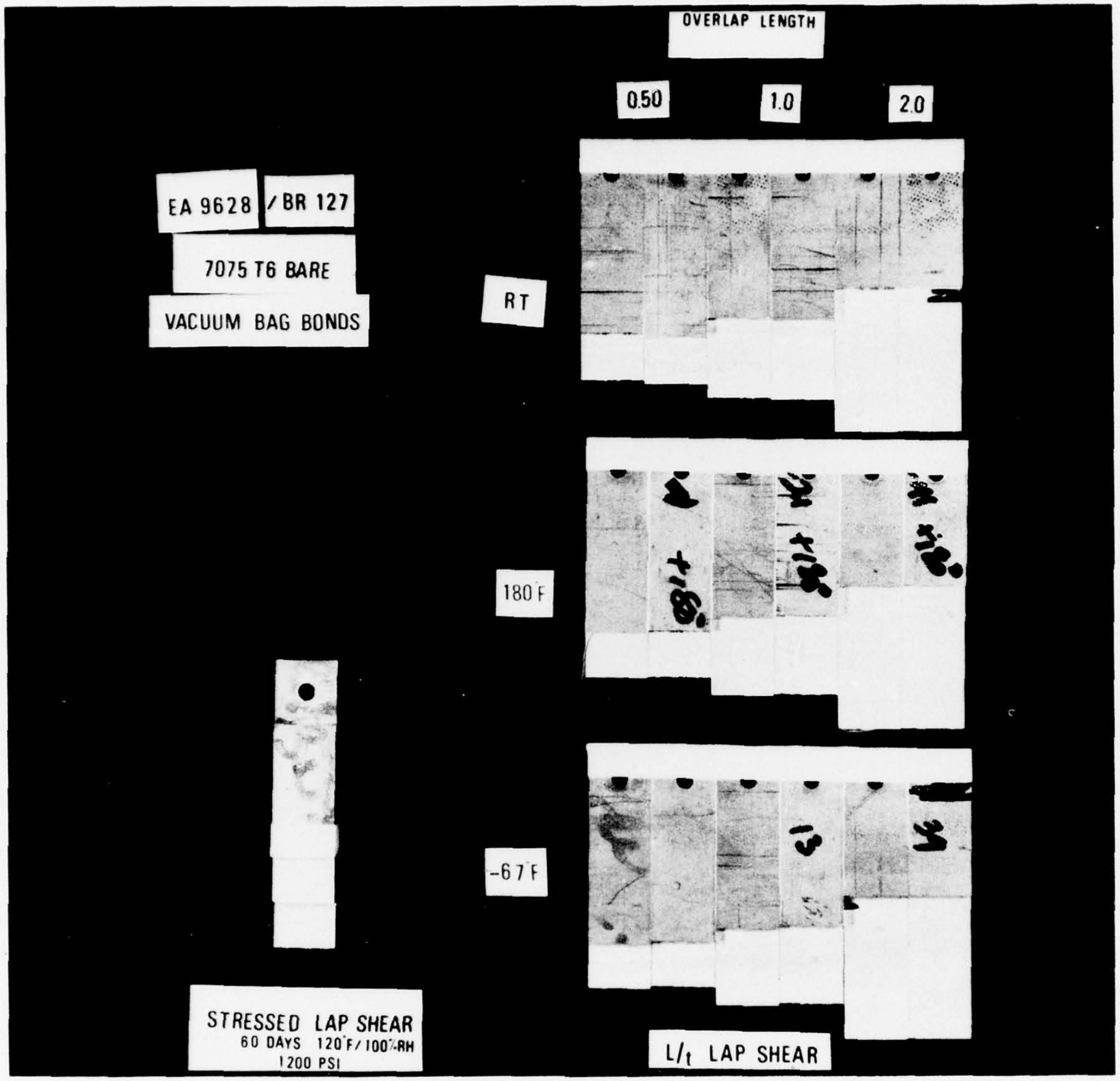


Figure 46.—Specimen Failure Surfaces—EA 9628, Optimized FPL Etch, Vacuum Bag Bonds

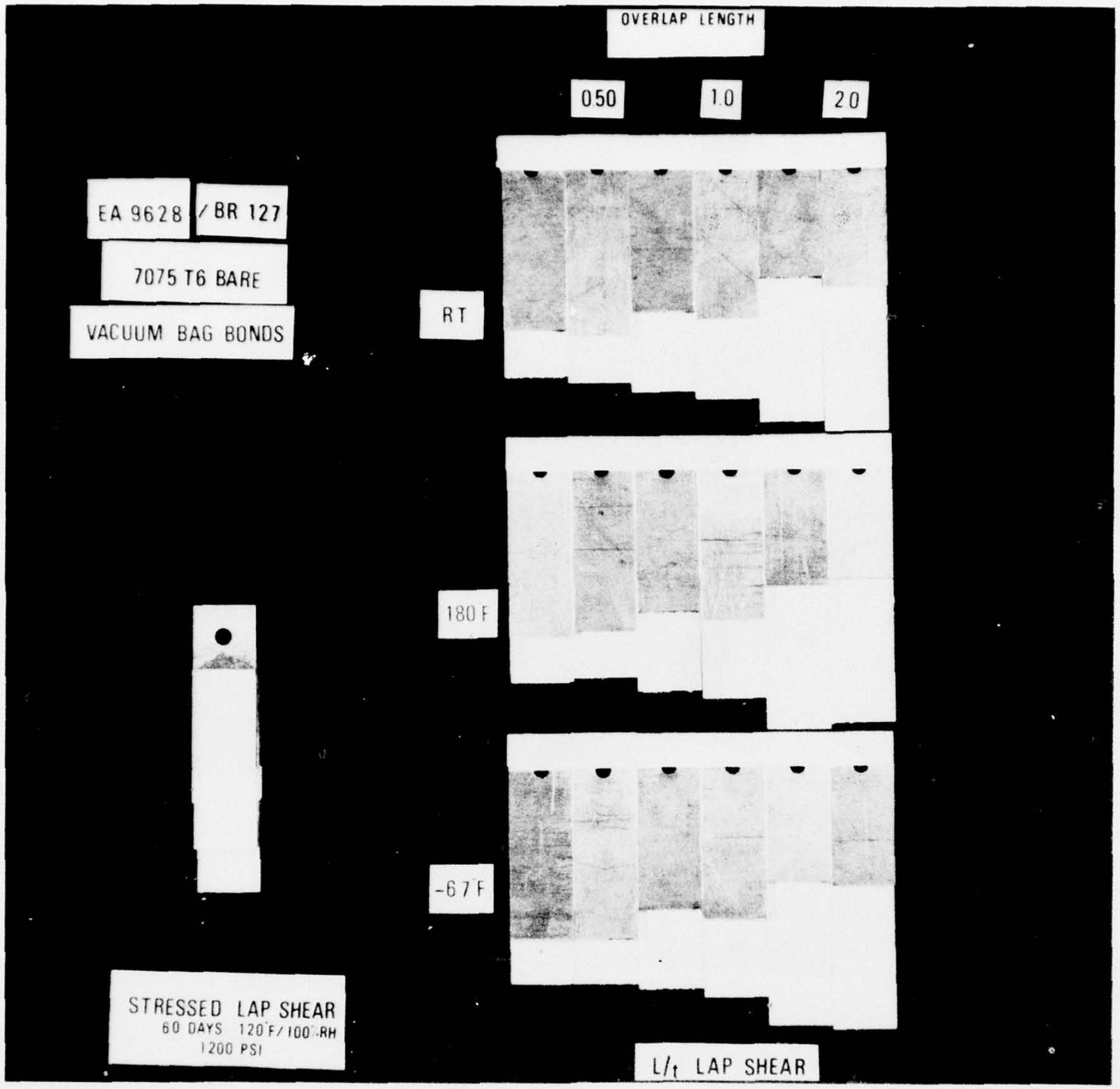


Figure 47.—Specimen Failure Surfaces—EA 9628, Non-Tank Anodized, Vacuum Bag Bonds

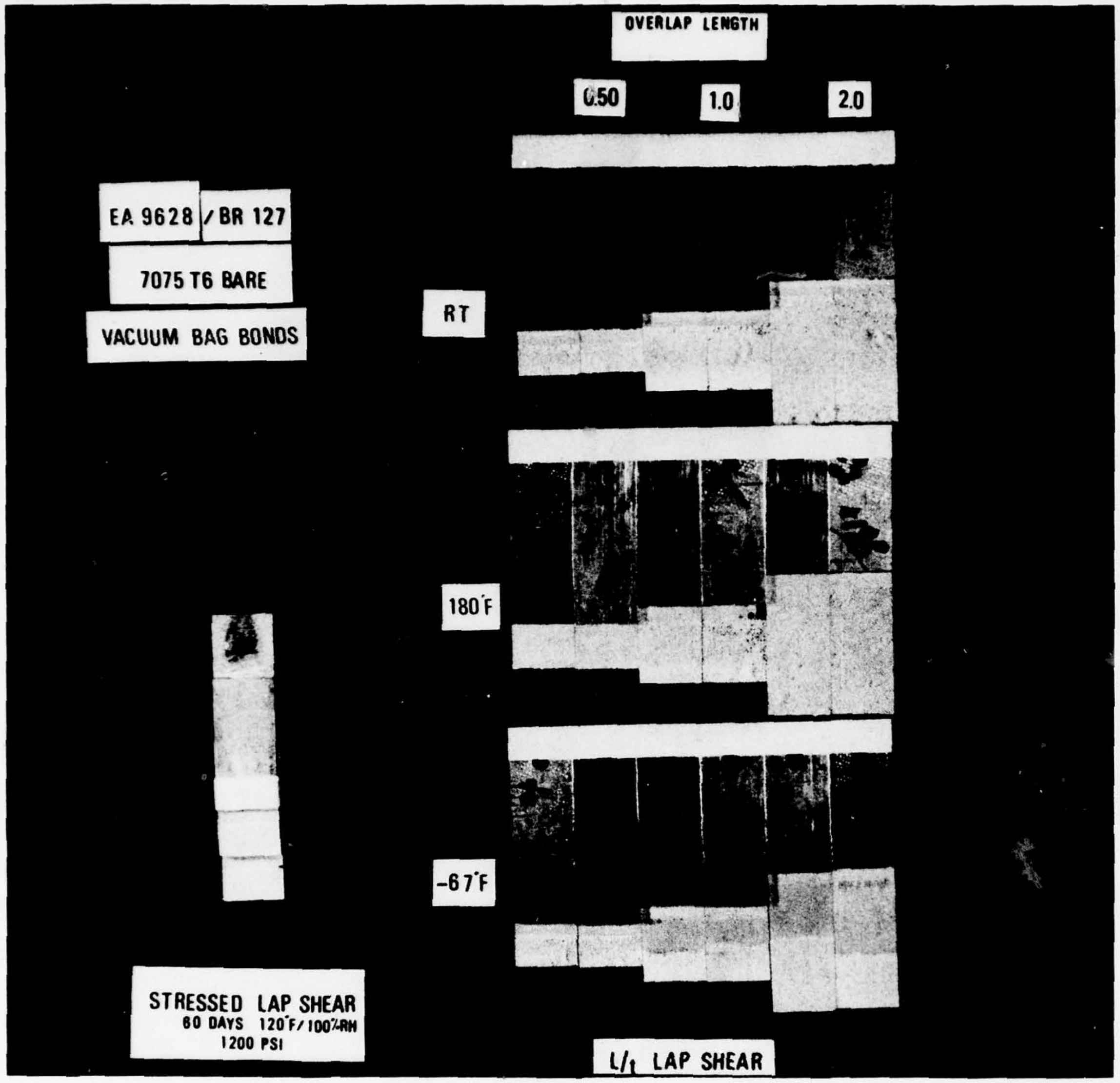


Figure 48.—Specimen Failure Surfaces—EA 9628, PasaJell 105, Vacuum Bag Bonds

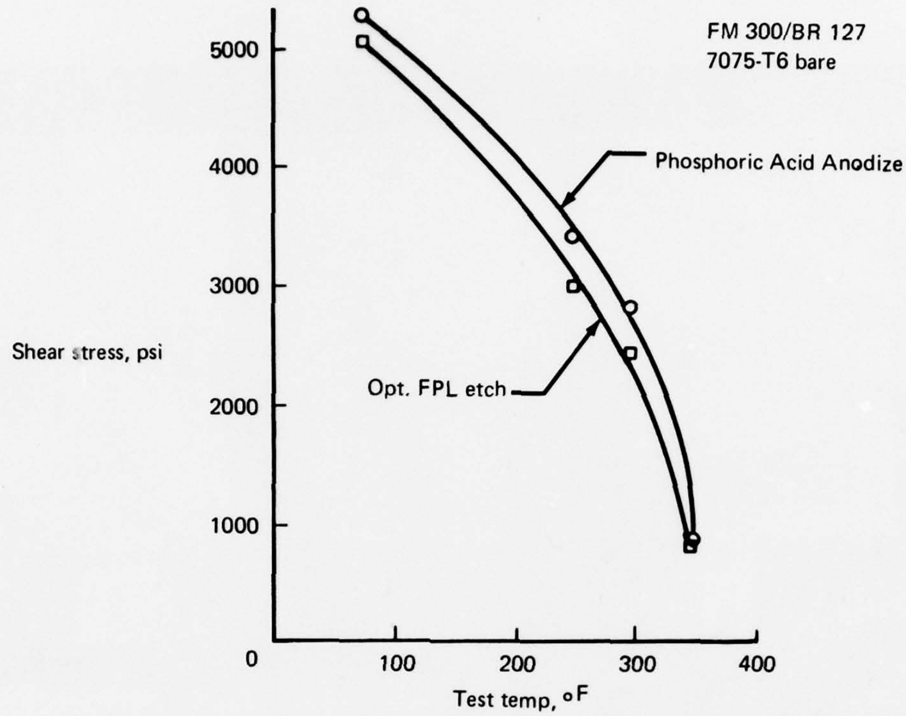


Figure 49.—Effect of Temperature on Shear Strength—With Primer, FM 300/BR 127

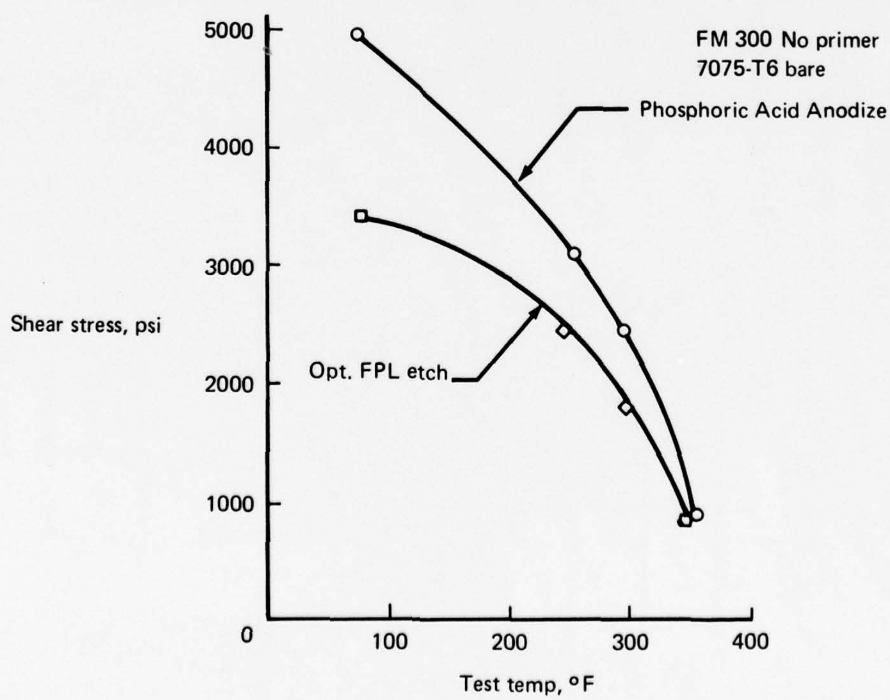


Figure 50.—Effect of Temperature on Shear Strength—No Primer, FM 300

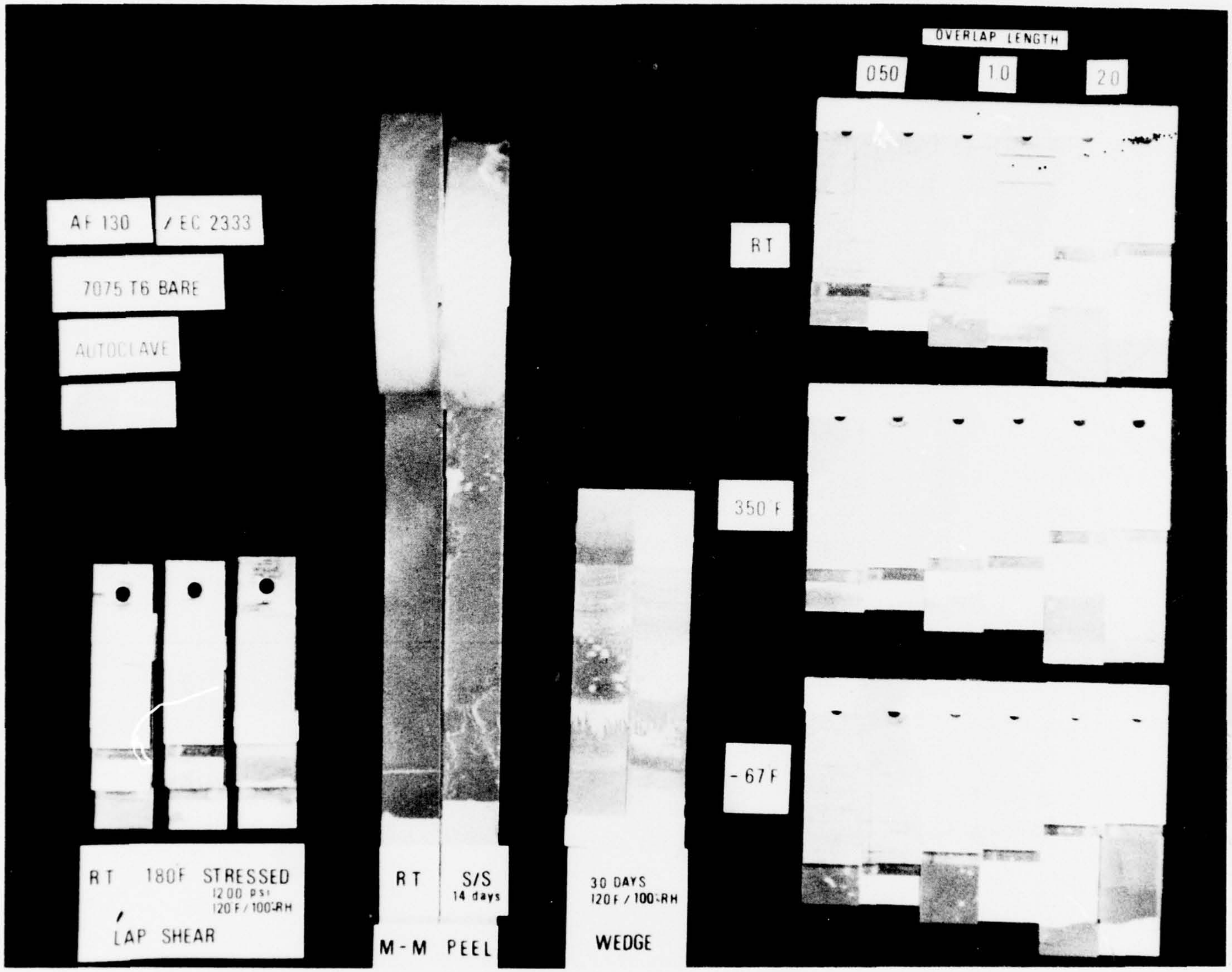


Figure 51.—Specimen Failure Surfaces—AF 130, Optimized FPL Etch, Autoclave Bonds

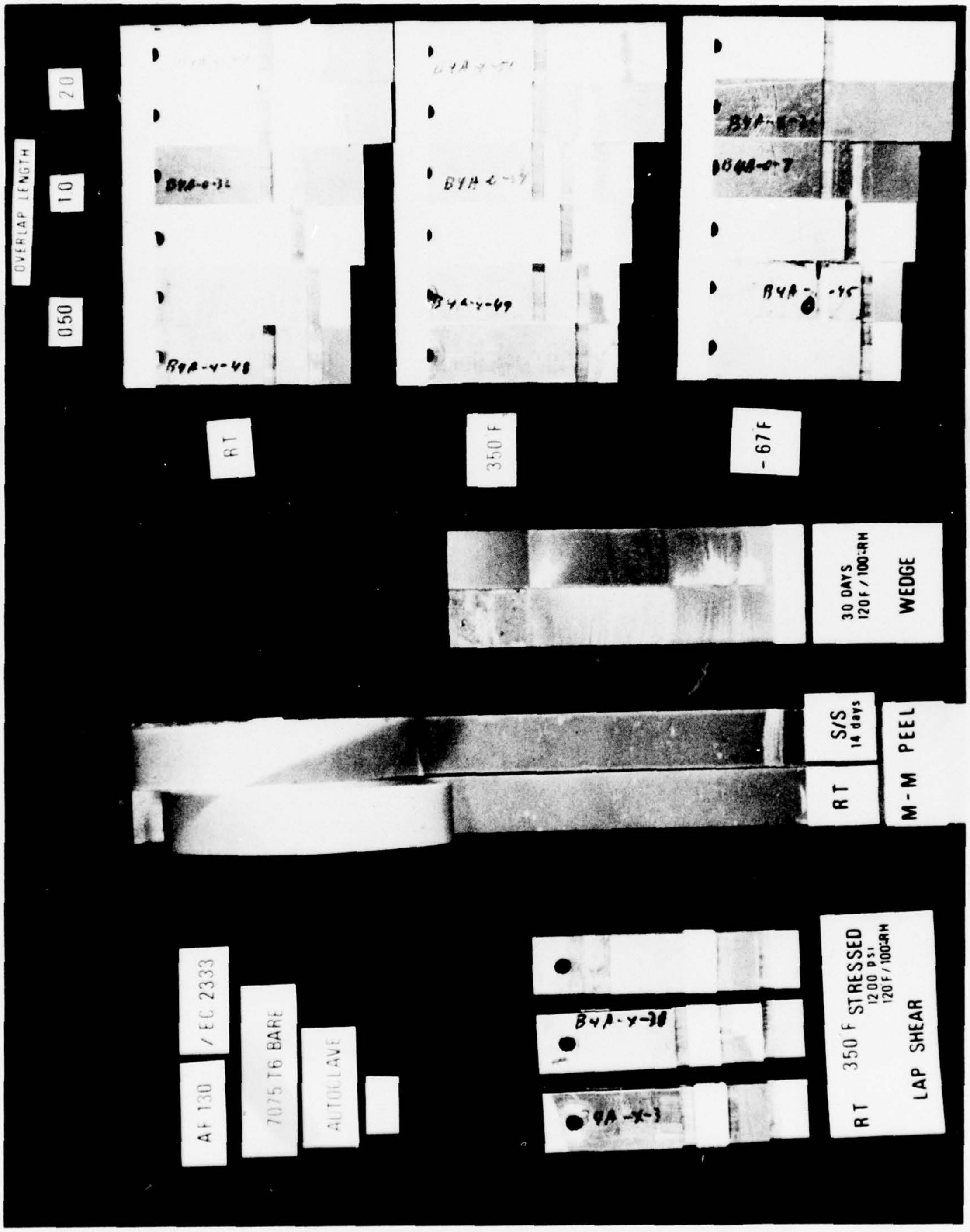


Figure 52.—Specimen Failure Surfaces—AF 130, Non-Tank Anodized, Autoclave Bonds

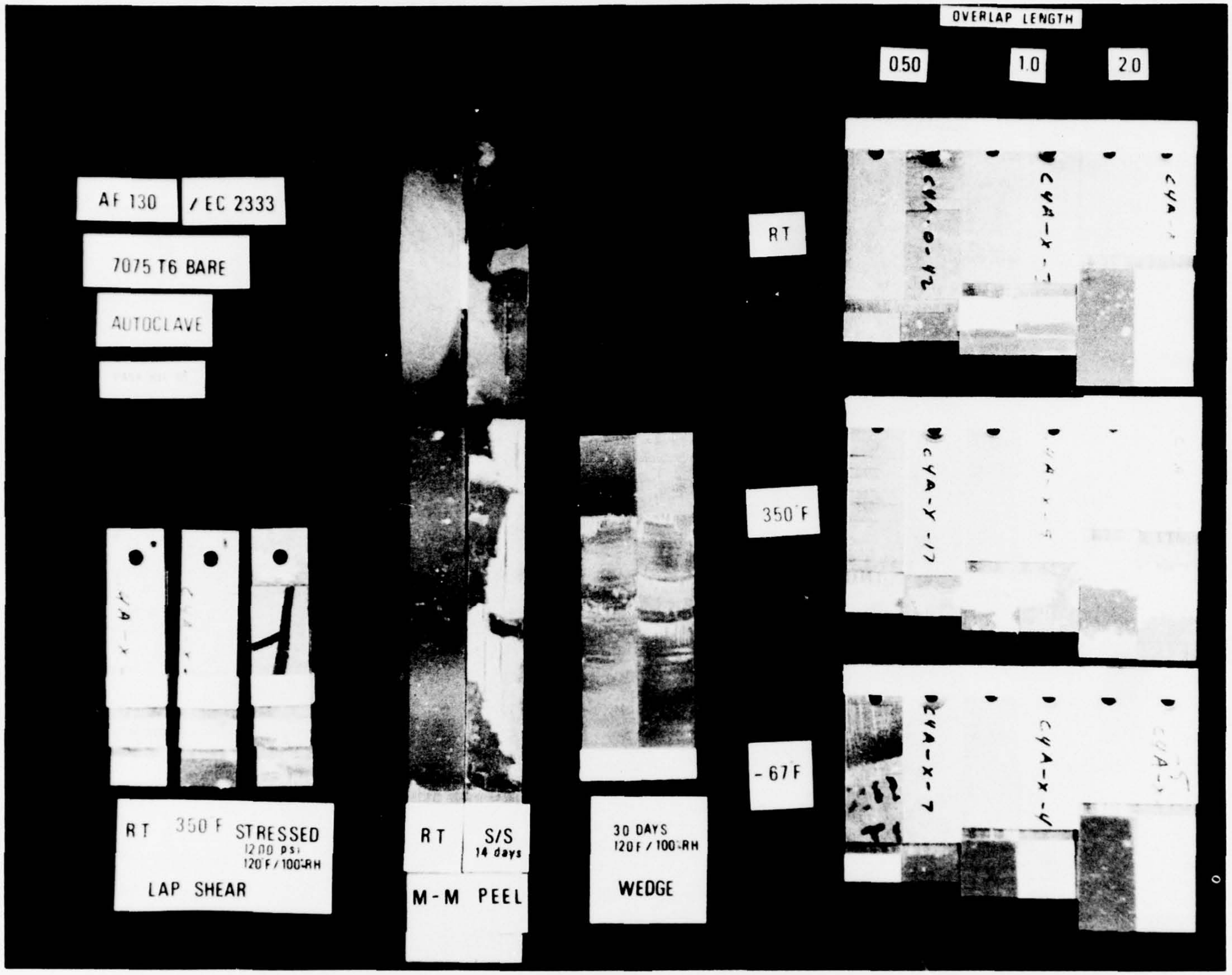


Figure 53.—Specimen Failure Surfaces—AF 130, PasaJell 105, Autoclave Bonds

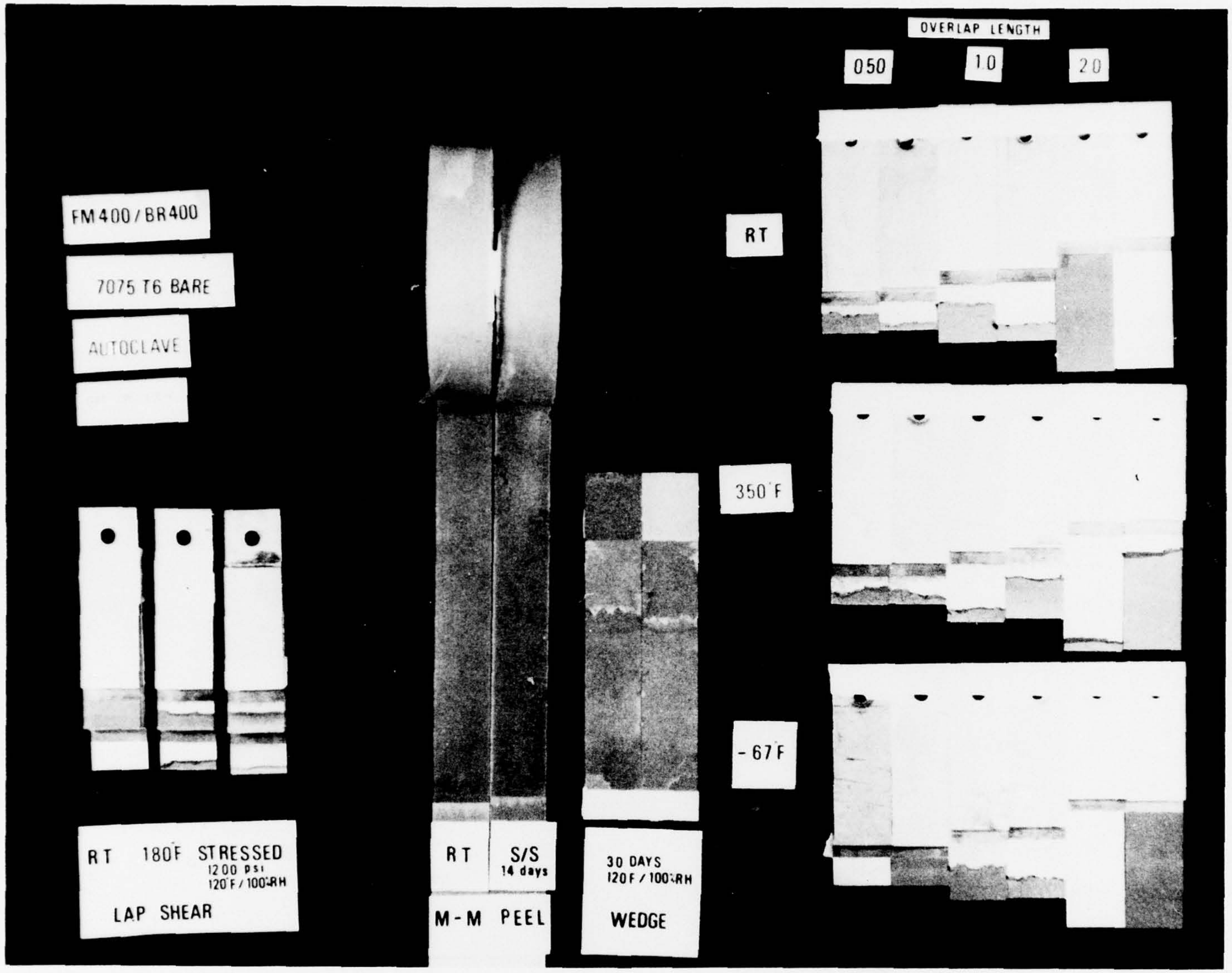


Figure 54.—Specimen Failure Surfaces—FM 400, Optimized FPL Etch, Autoclave Bonds

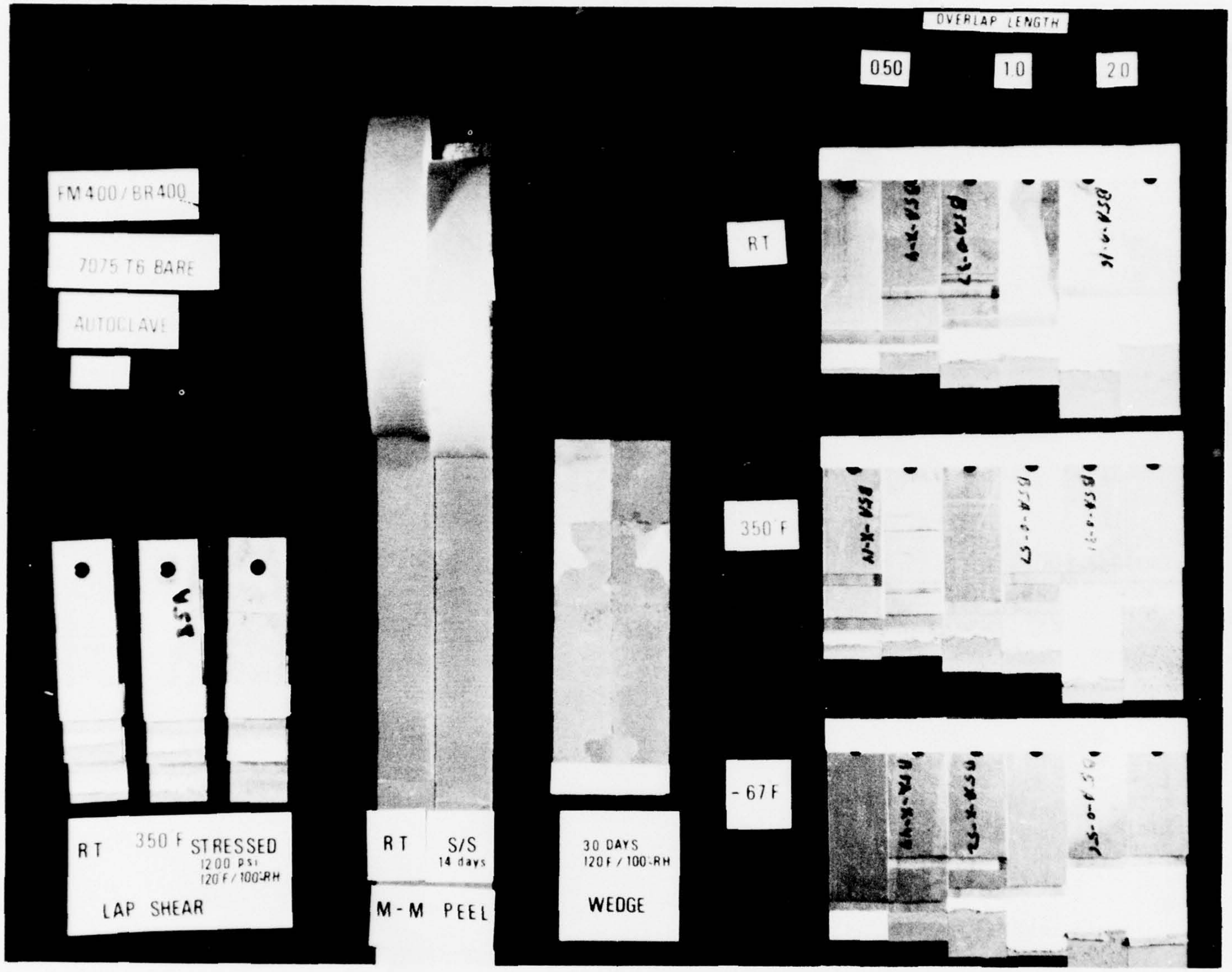


Figure 55.—Specimen Failure Surfaces—FM 400, Non-Tank Anodized, Autoclave Bonds

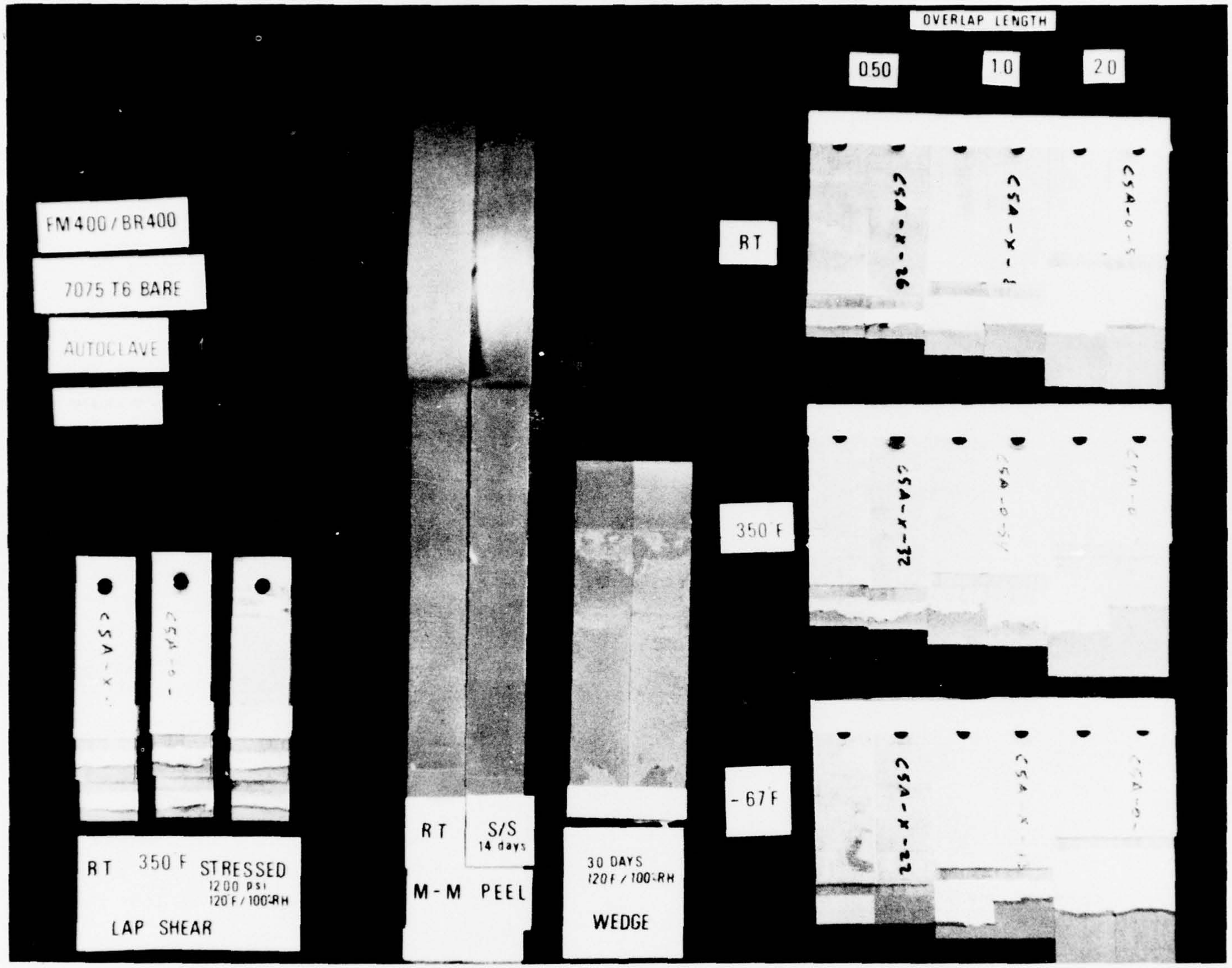


Figure 56.—Specimen Failure Surfaces—FM 400, PasaJell 105, Autoclave Bonds

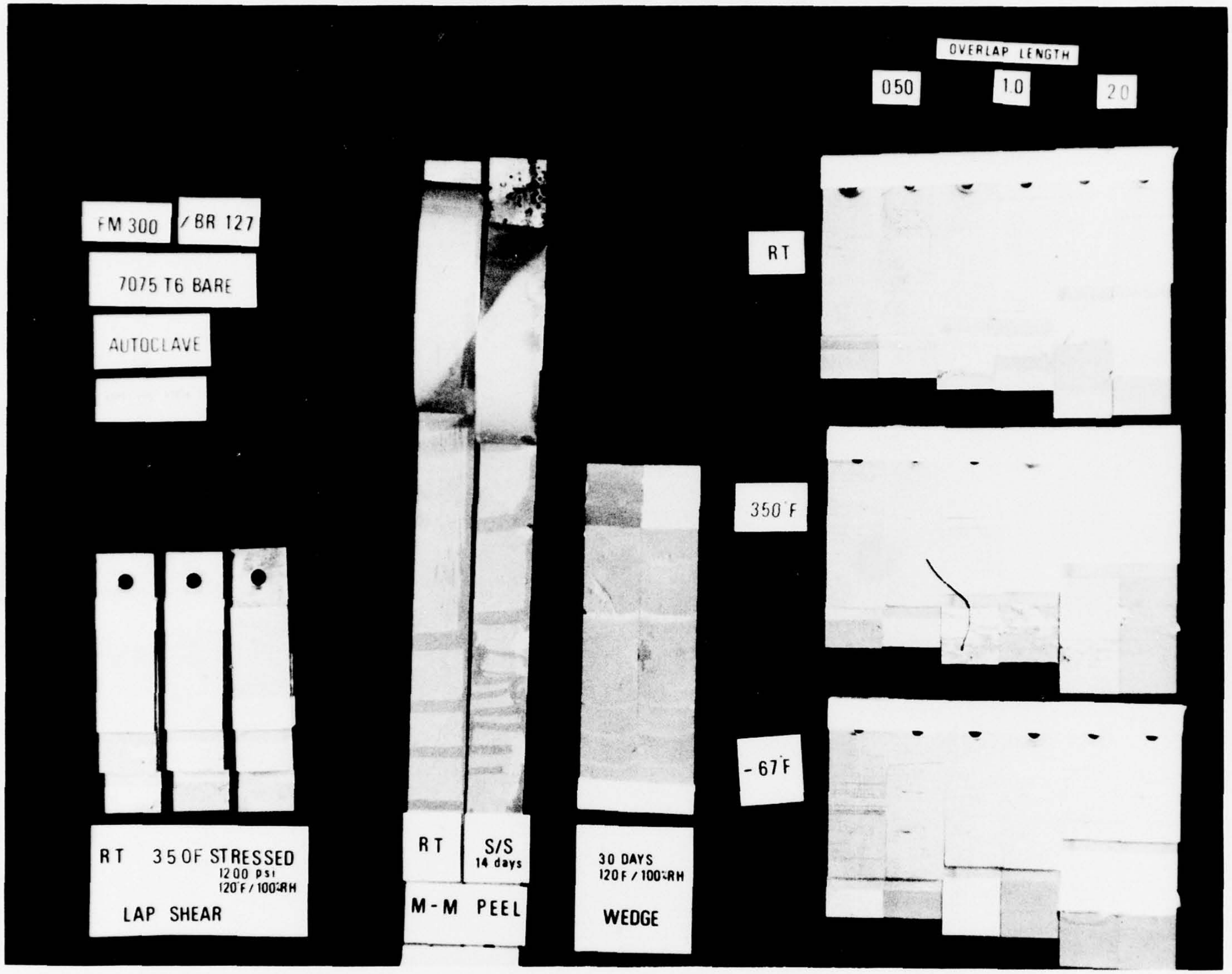


Figure 57.—Specimen Failure Surfaces—FM 300, Optimized FPL Etch, Autoclave Bonds

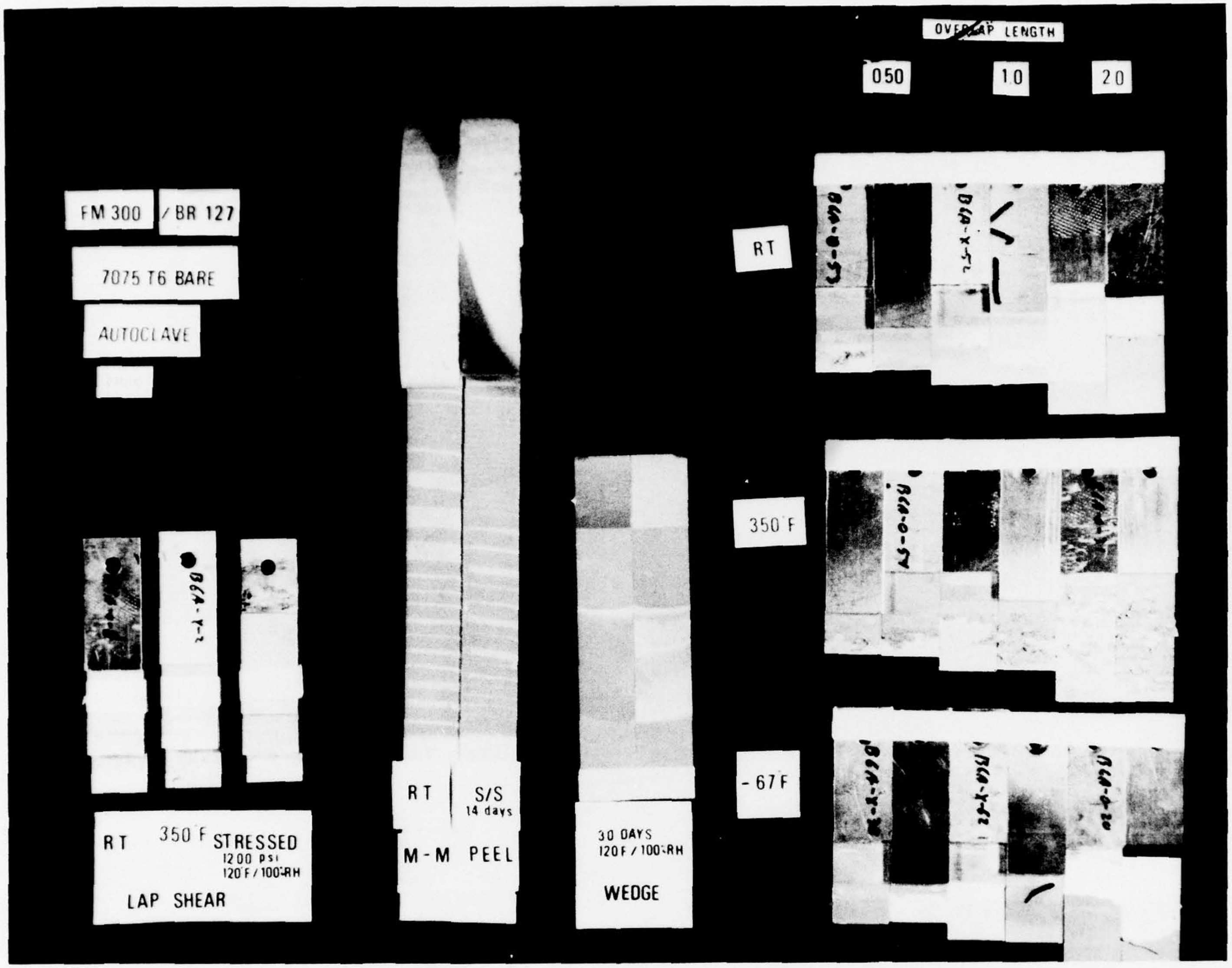


Figure 58.—Specimen Failure Surfaces—FM 300,Non-Tank Anodized, Autoclave Bonds

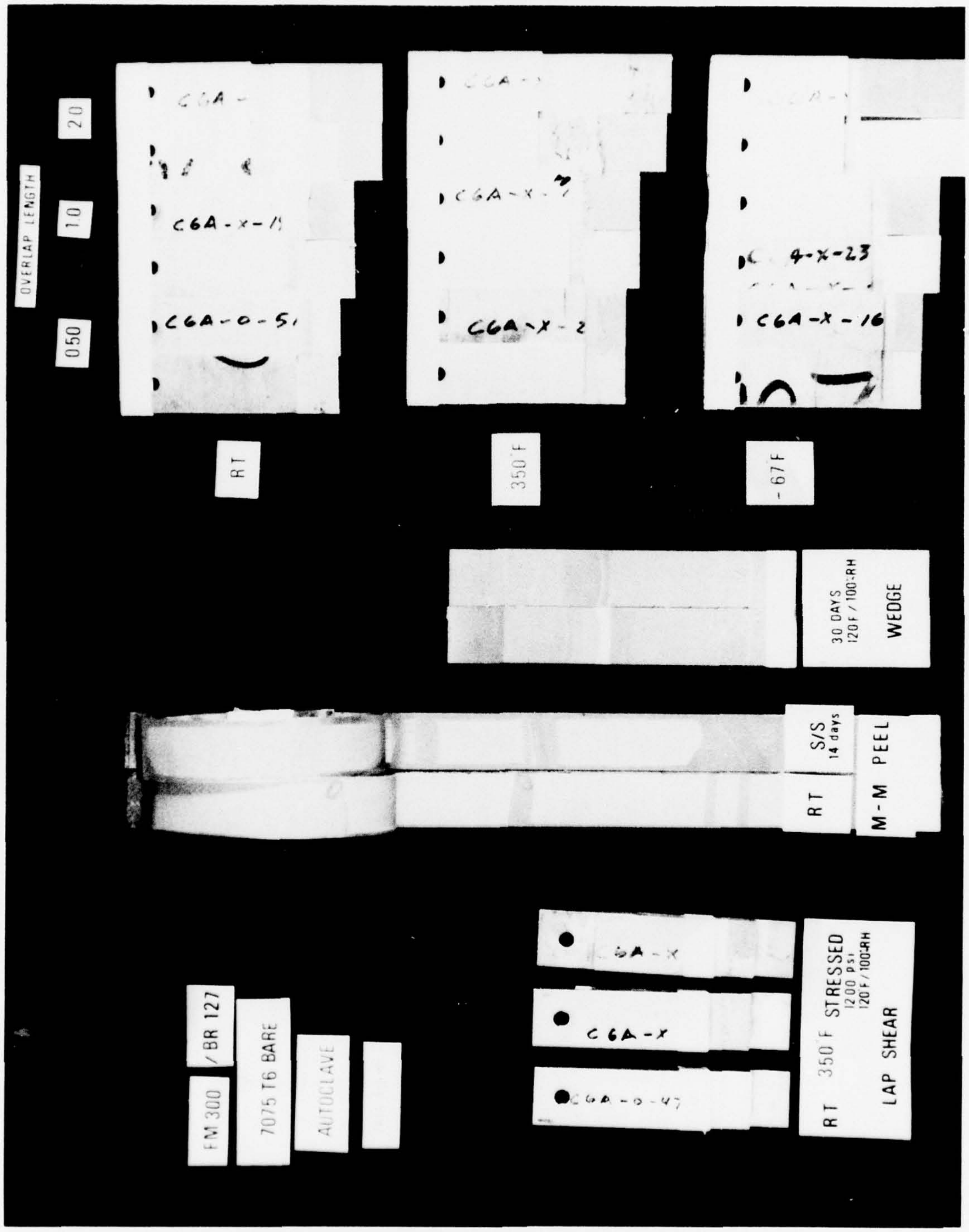


Figure 59.—Specimen Failure Surfaces—FM 300, PasaJell 105, Autoclave Bonds

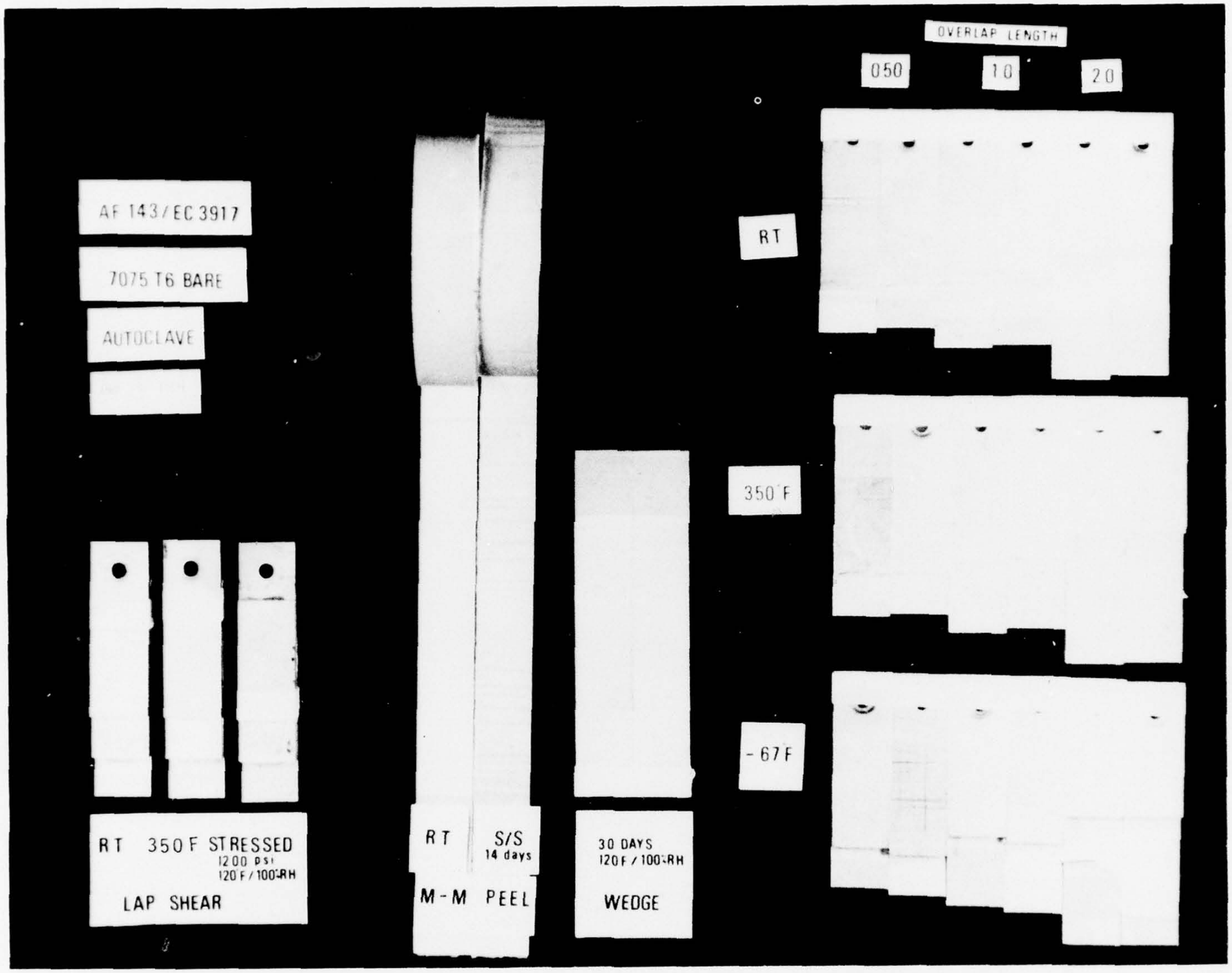


Figure 60.—Specimen Failure Surfaces—AF 143, Optimized FPL Etch, Autoclave Bonds

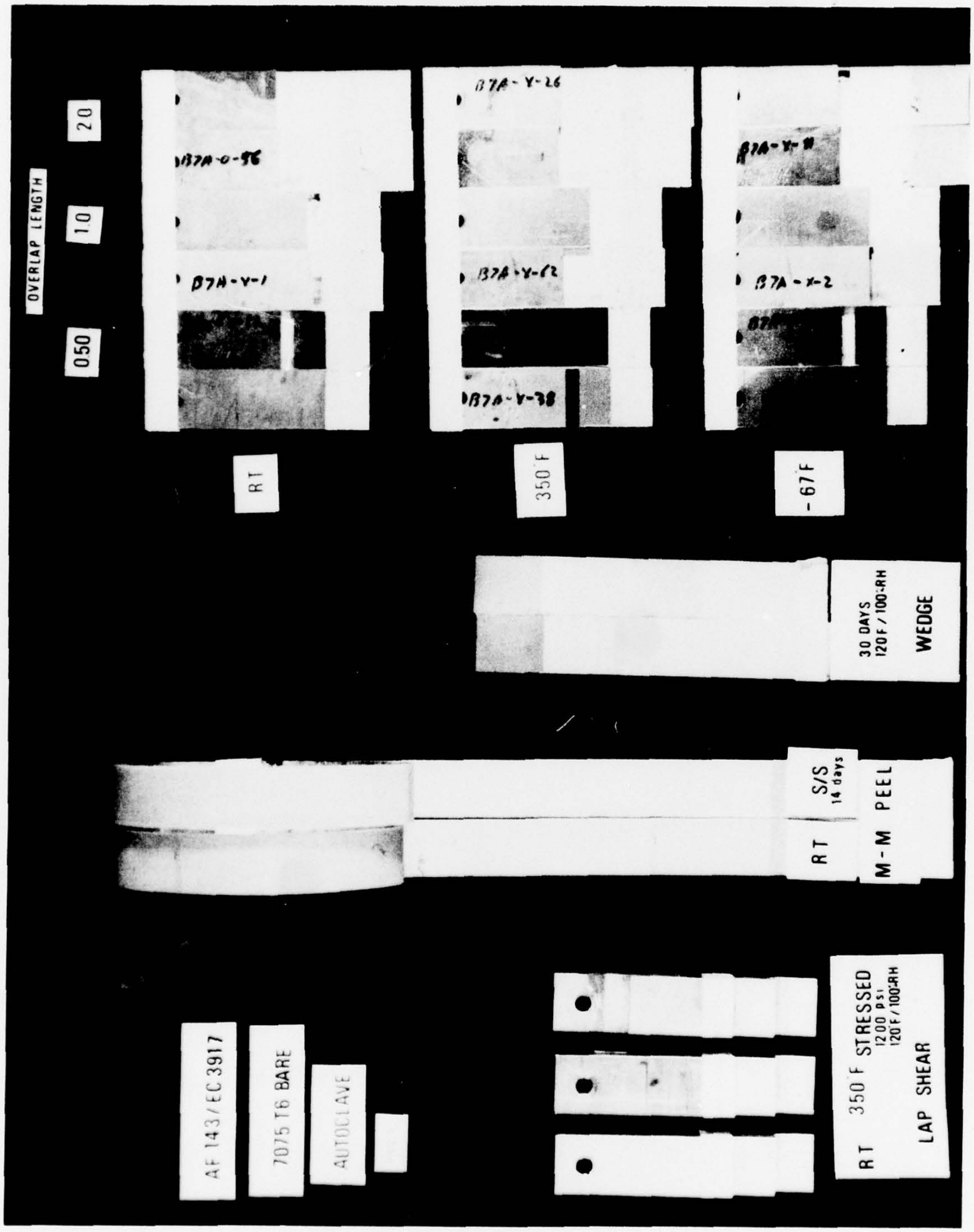


Figure 61.—Specimen Failure Surfaces—AF 143, Non-Tank Anodized, Autoclave Bonds

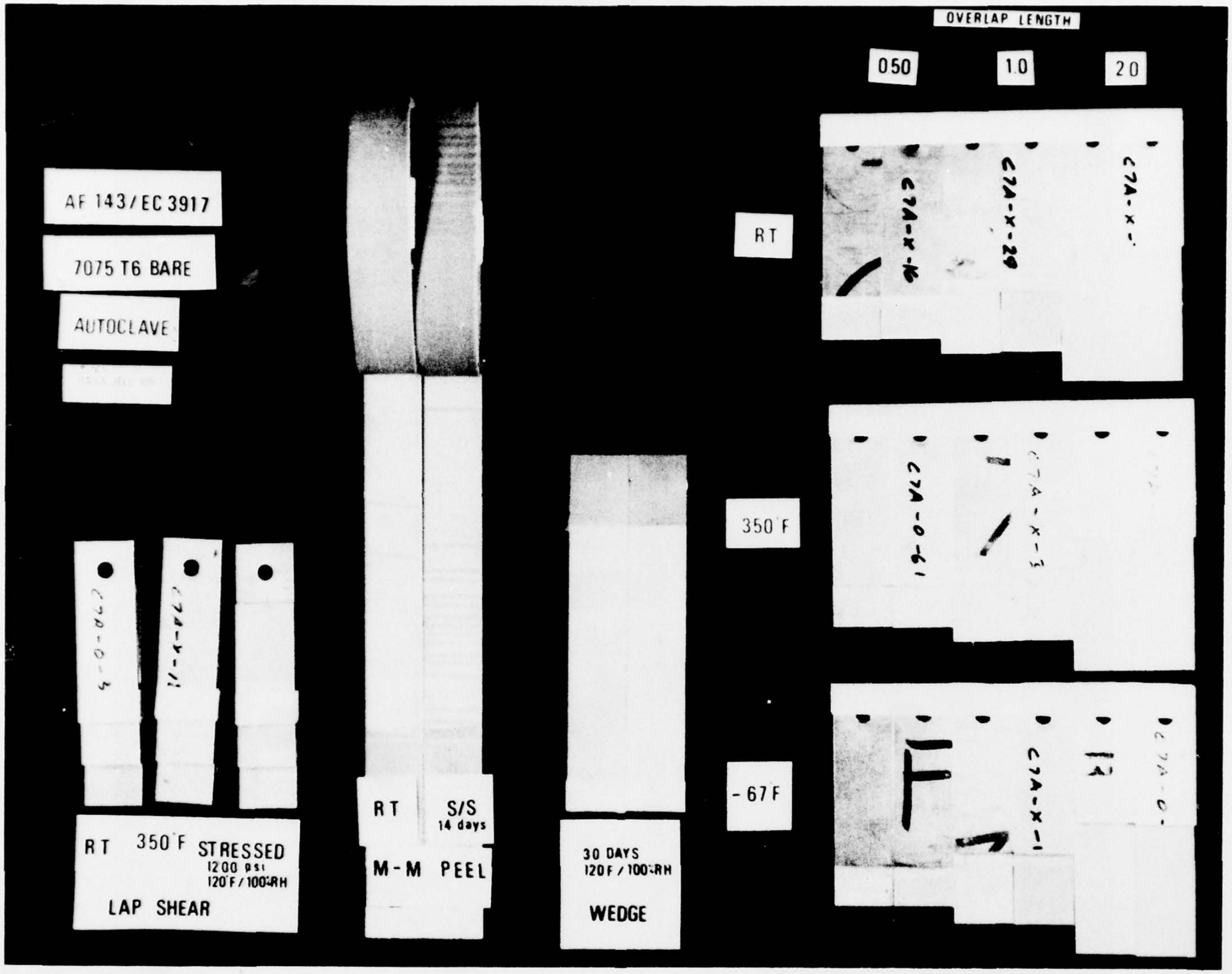


Figure 62.—Specimen Failure Surfaces—AF 143, PasaJell 105, Autoclave Bonds

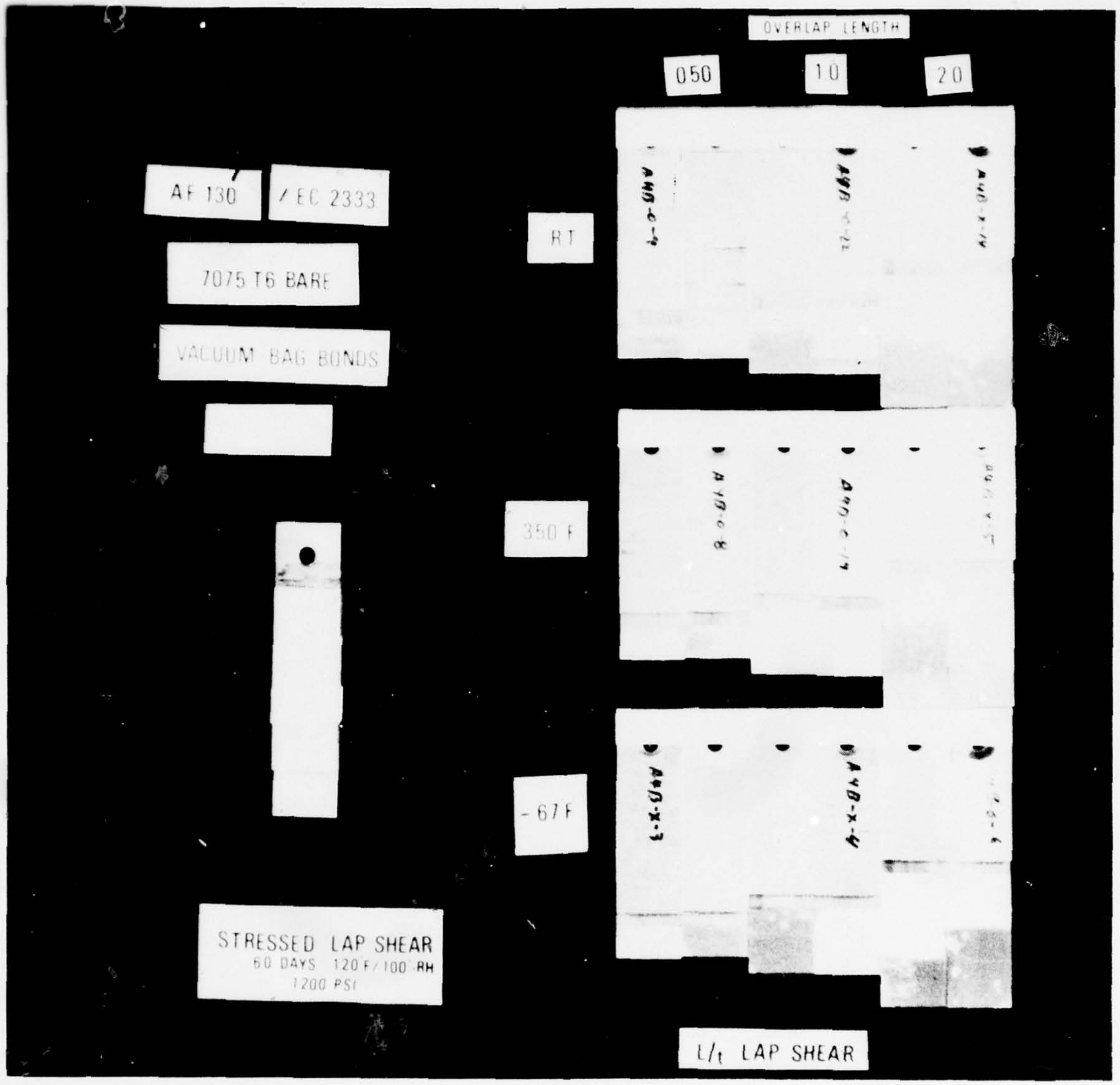


Figure 63.—Specimen Failure Surfaces—AF 130, Optimized FPL Etch, Vacuum Bag Bonds

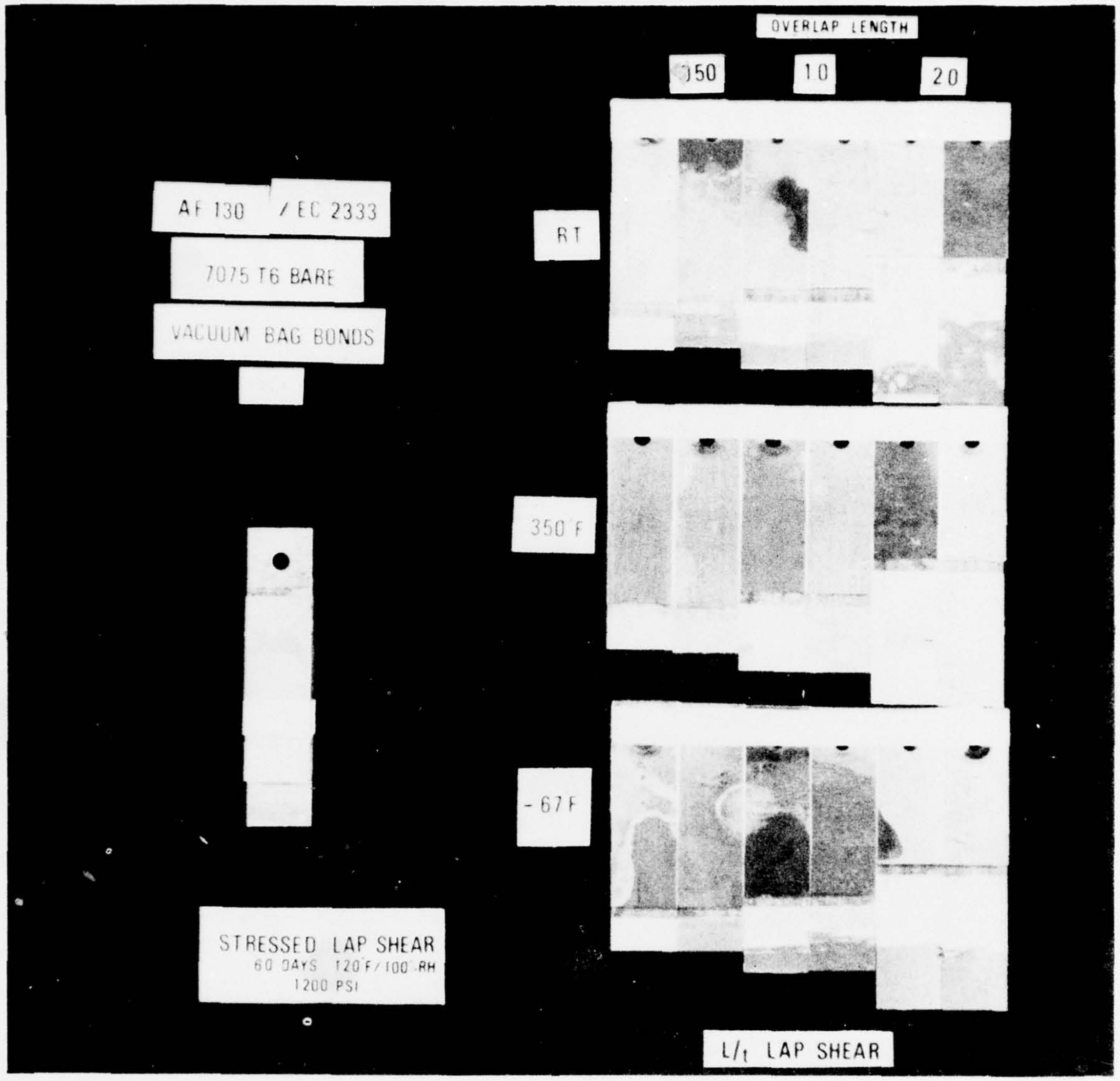


Figure 64.—Specimen Failure Surfaces—AF 130, Non-Tank Anodized, Vacuum Bag Bonds

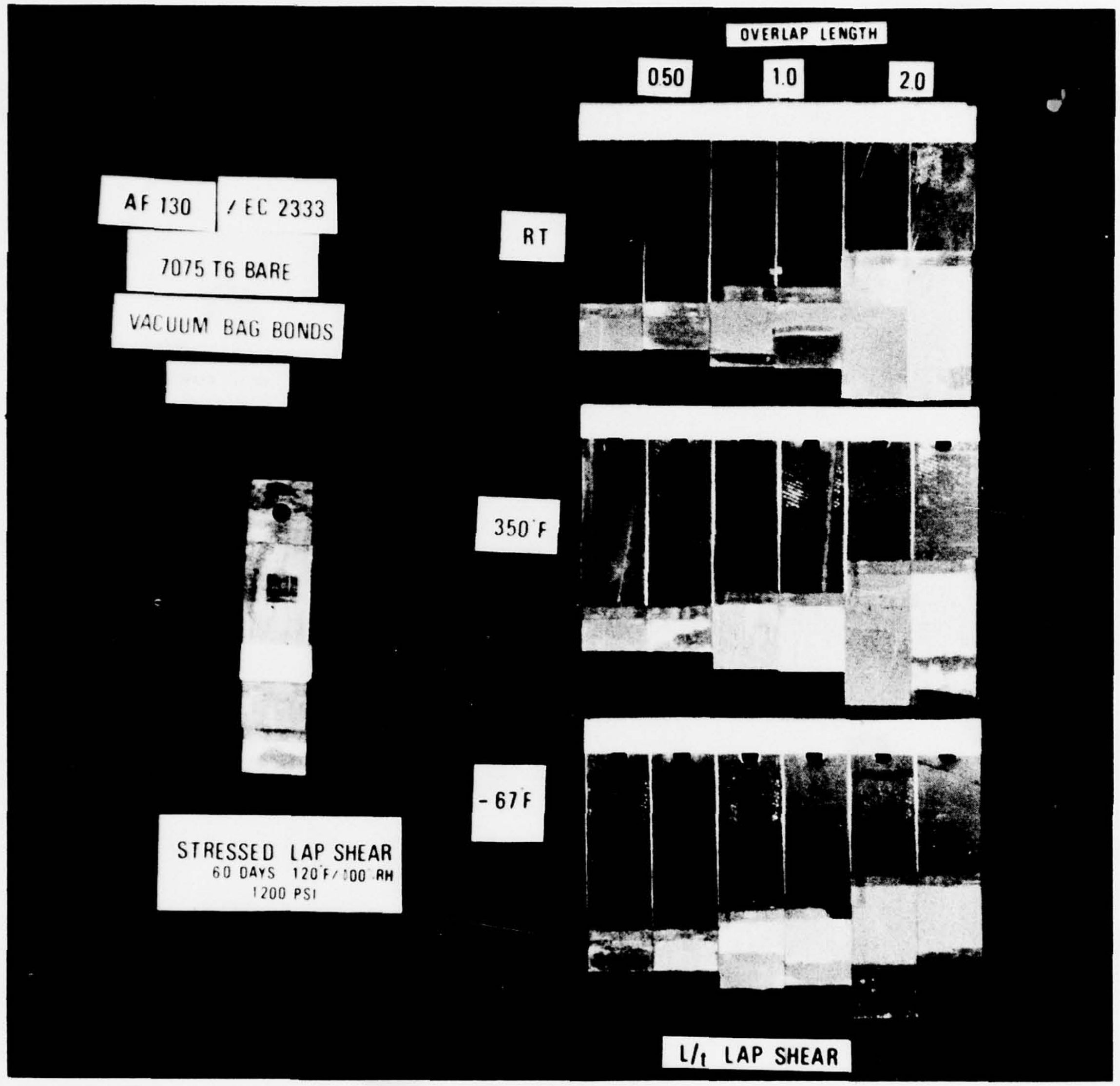


Figure 65.—Specimen Failure Surfaces—AF 130, PasaJell 105, Vacuum Bag Bonds

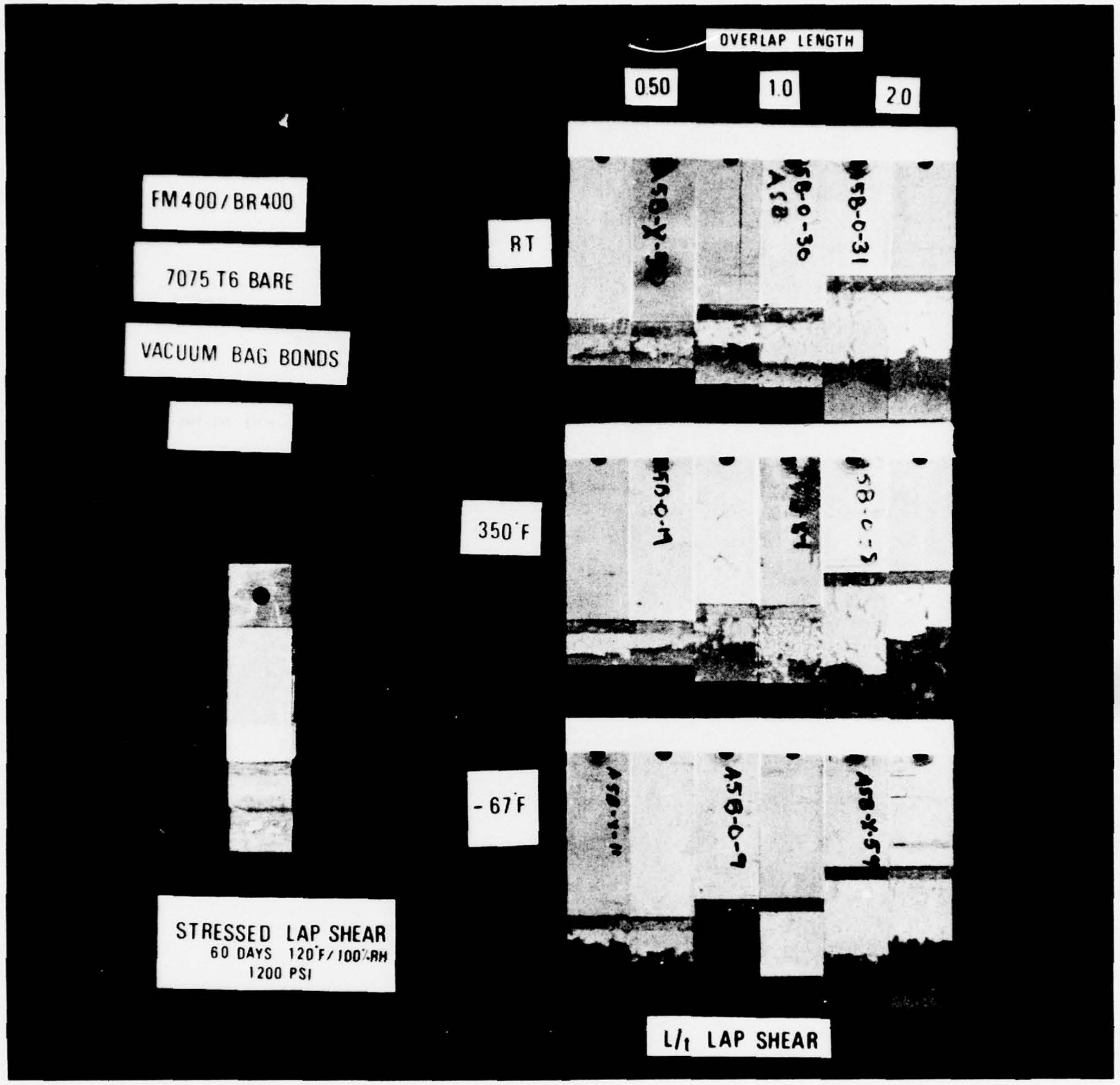


Figure 66.—Specimen Failure Surfaces—FM 400, Optimized FPL Etch, Vacuum Bag Bonds

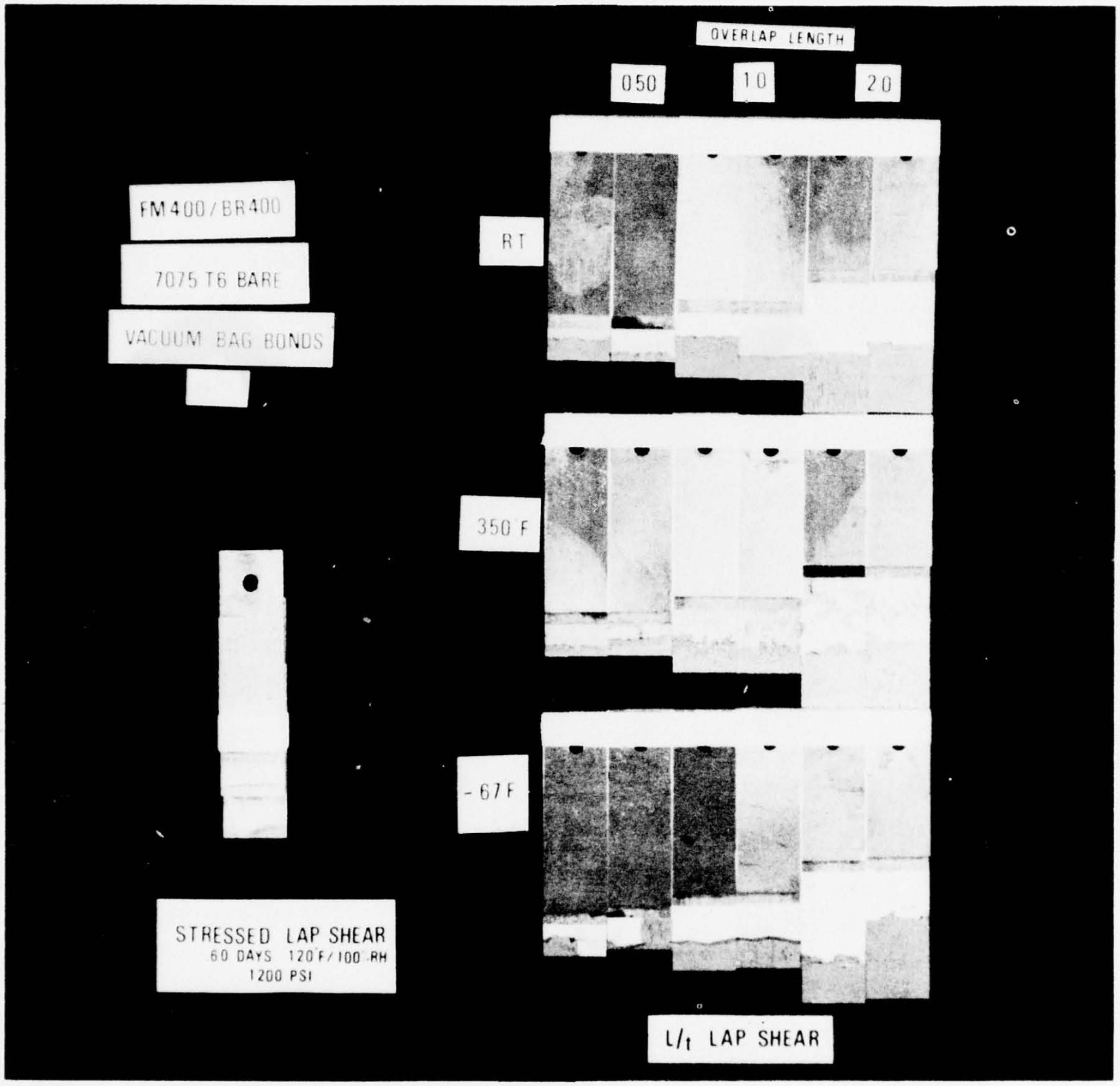


Figure 67.—Specimen Failure Surfaces—FM 400, Non-Tank Anodized, Vacuum Bag Bonds

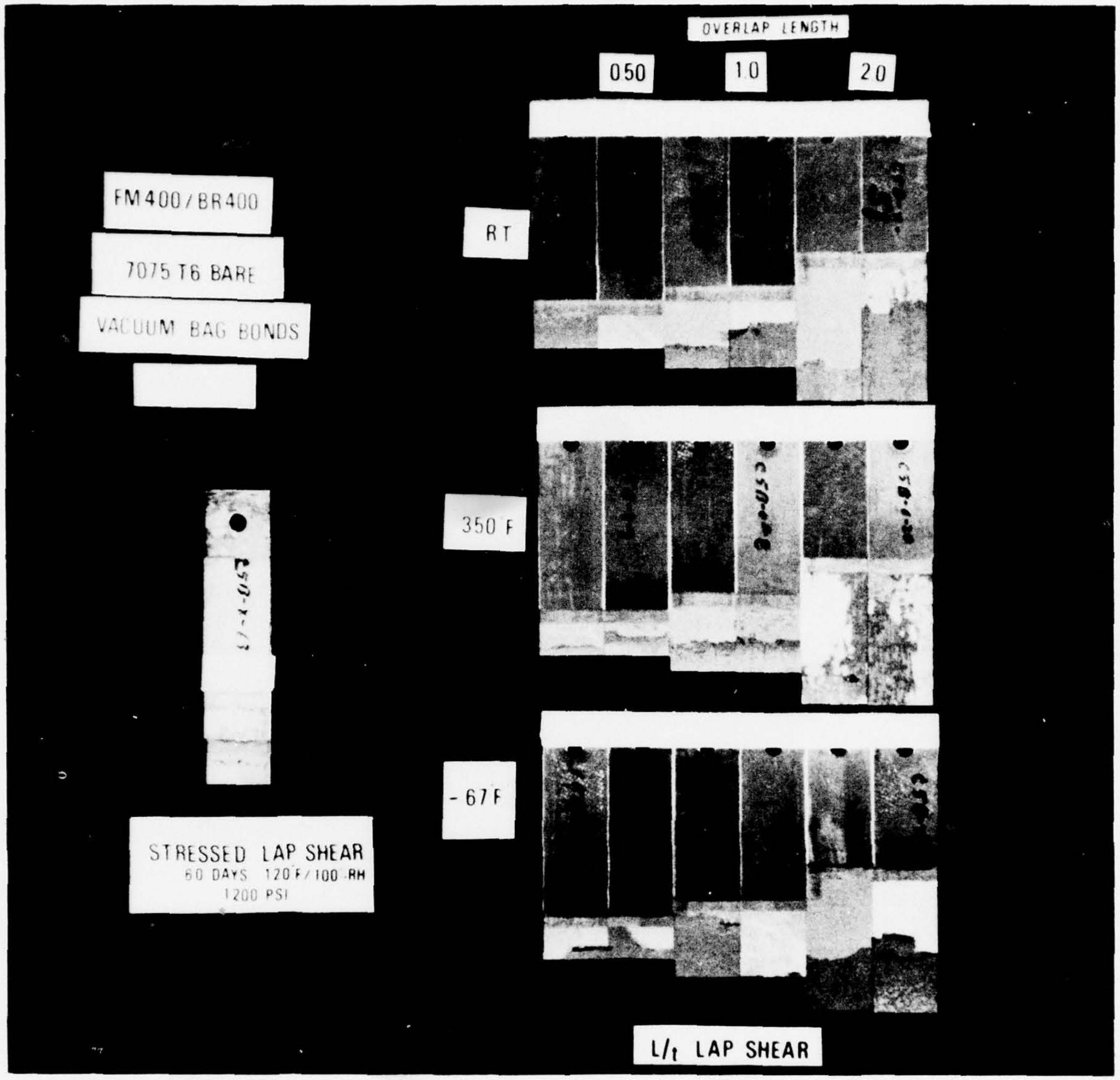


Figure 68.—Specimen Failure Surfaces—FM 400, PasaJell 105, Vacuum Bag Bonds

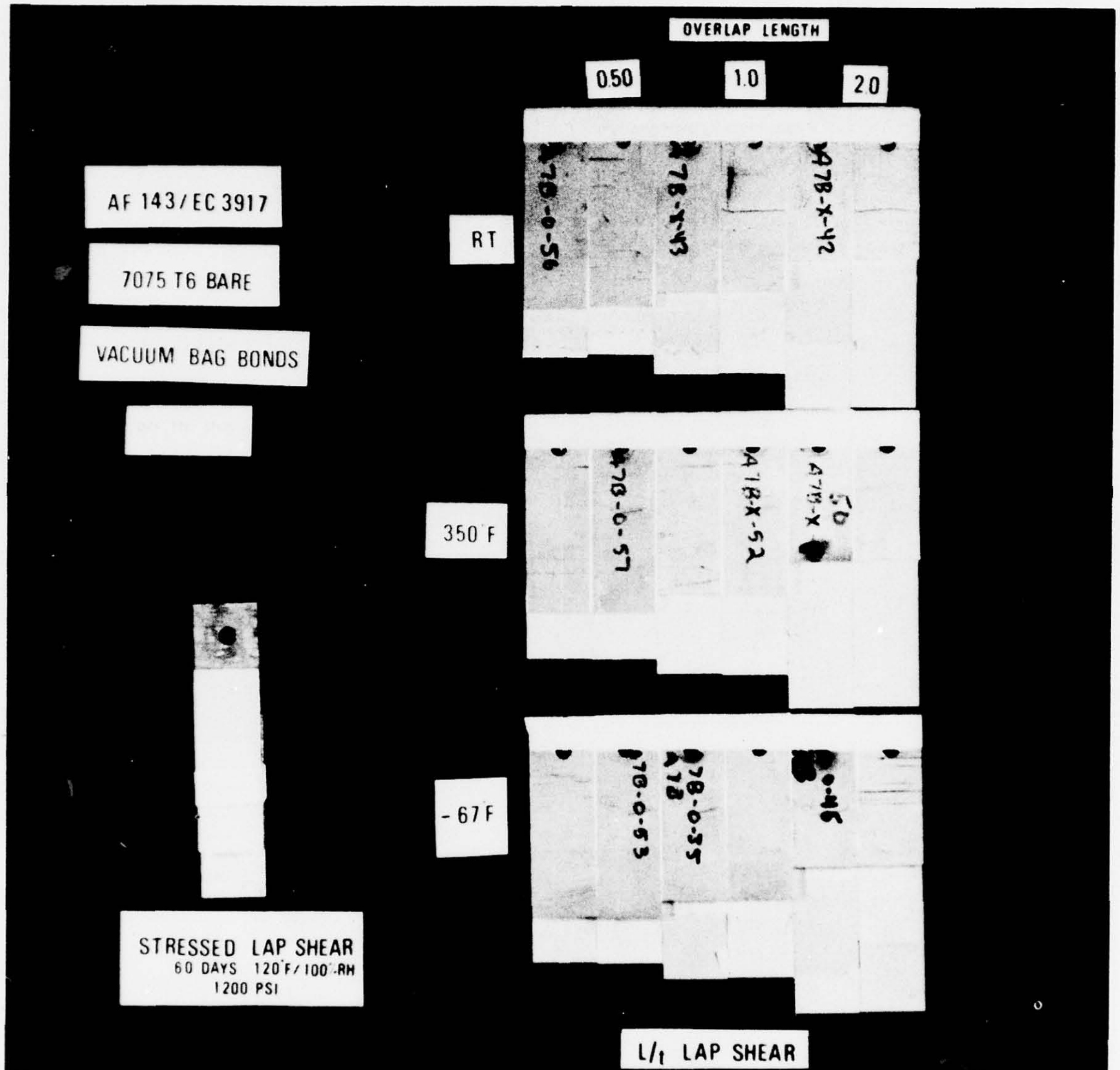


Figure 69.—Specimen Failure Surfaces—AF 143, Optimized FPL Etch, Vacuum Bag Bonds

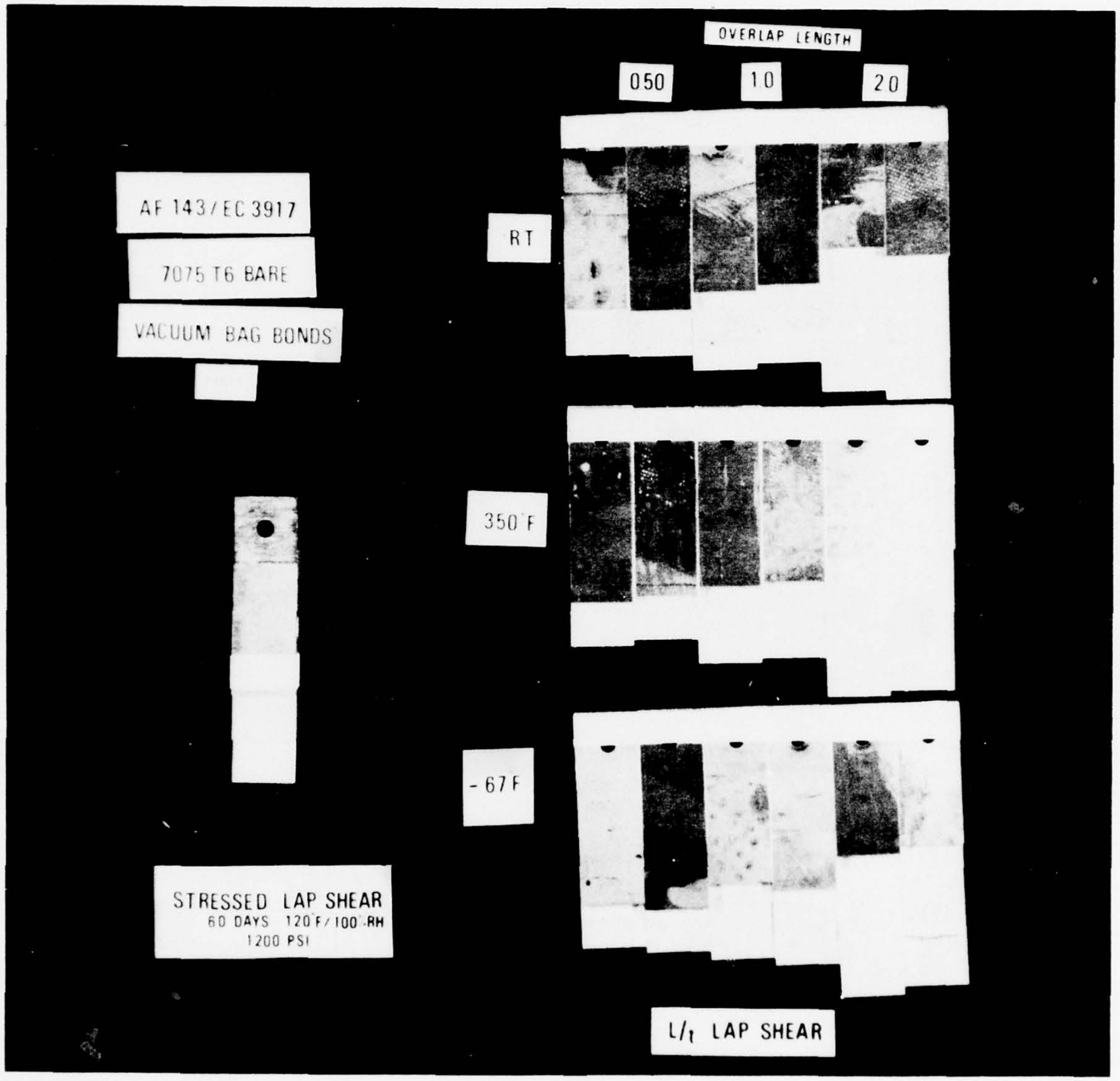


Figure 70.—Specimen Failure Surfaces—AF 143, Non-Tank Anodized, Vacuum Bag Bonds

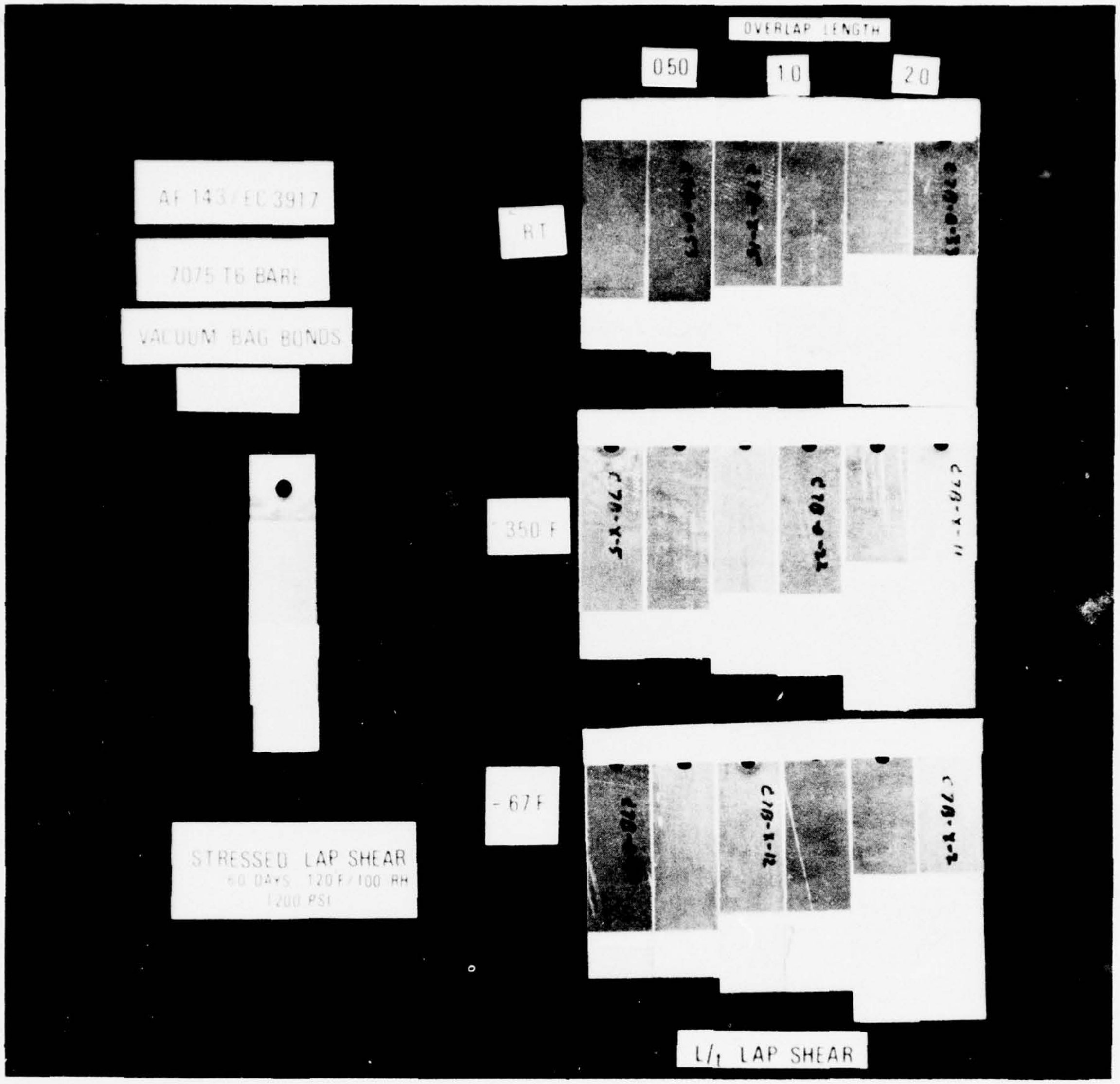


Figure 71.—Specimen Failure Surfaces—AF 143, PasaJell 105, Vacuum Bag Bonds

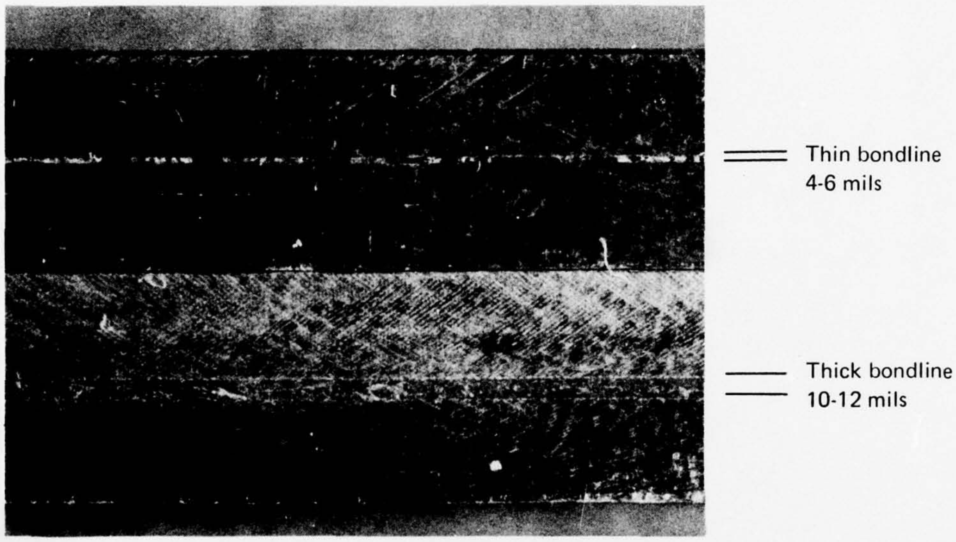


Figure 72.—Bondline Thickness Comparison—RT Cure Bonds

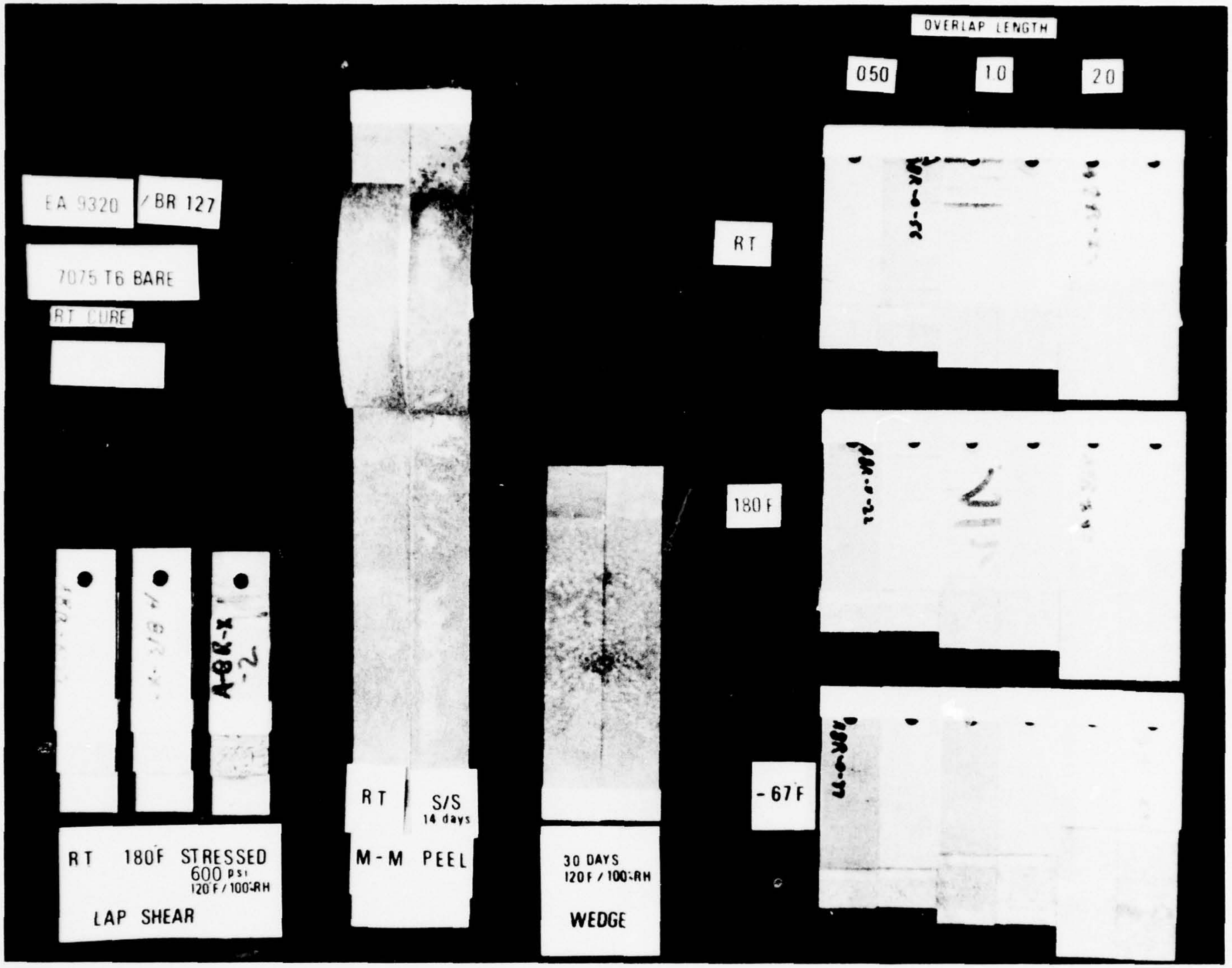


Figure 73.—Specimen Failure Surfaces—EA 9320, Optimized FPL Etch, RT Bonds

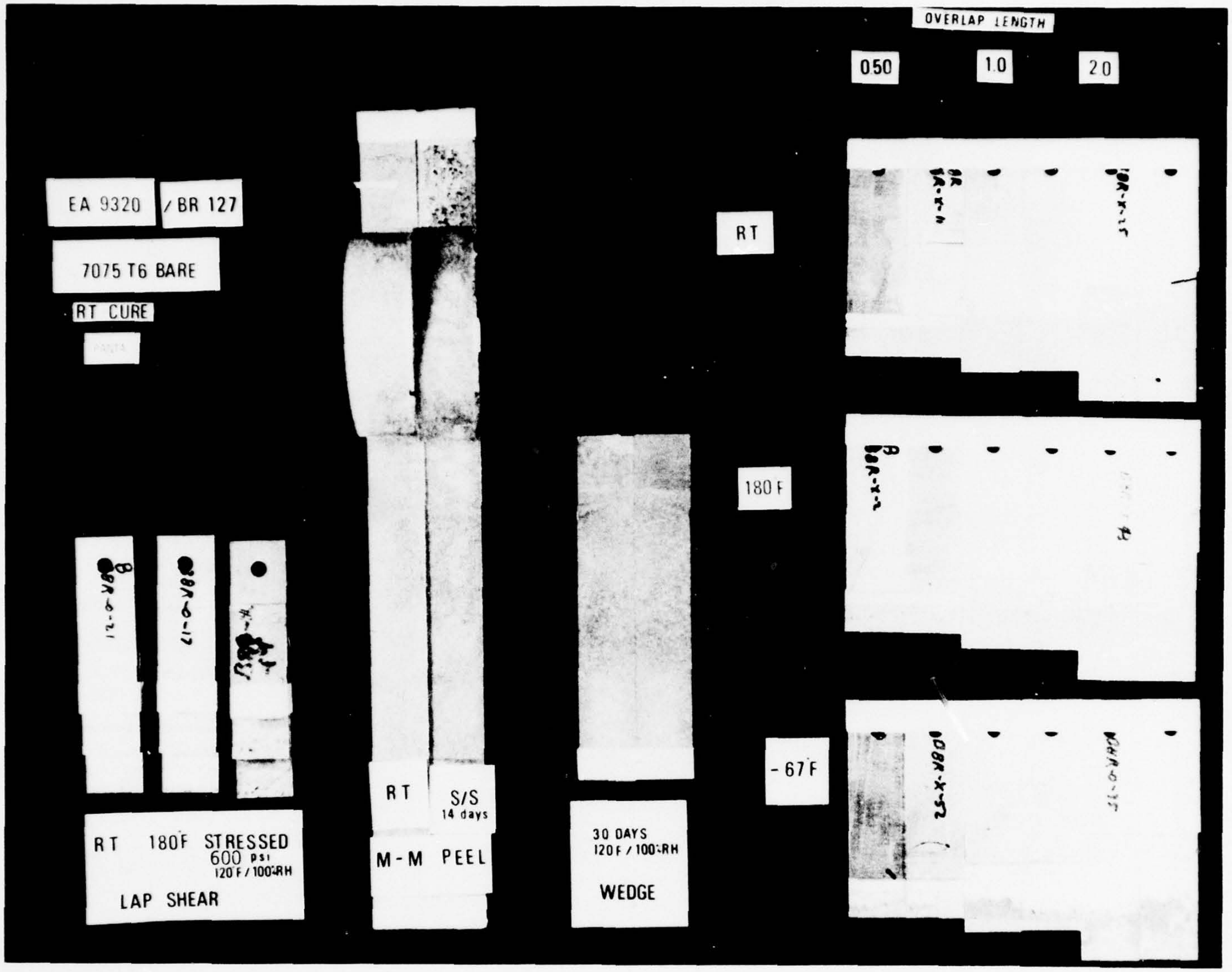


Figure 74.—Specimen Failure Surfaces—EA 9320, Non-Tank Anodized, RT Bonds

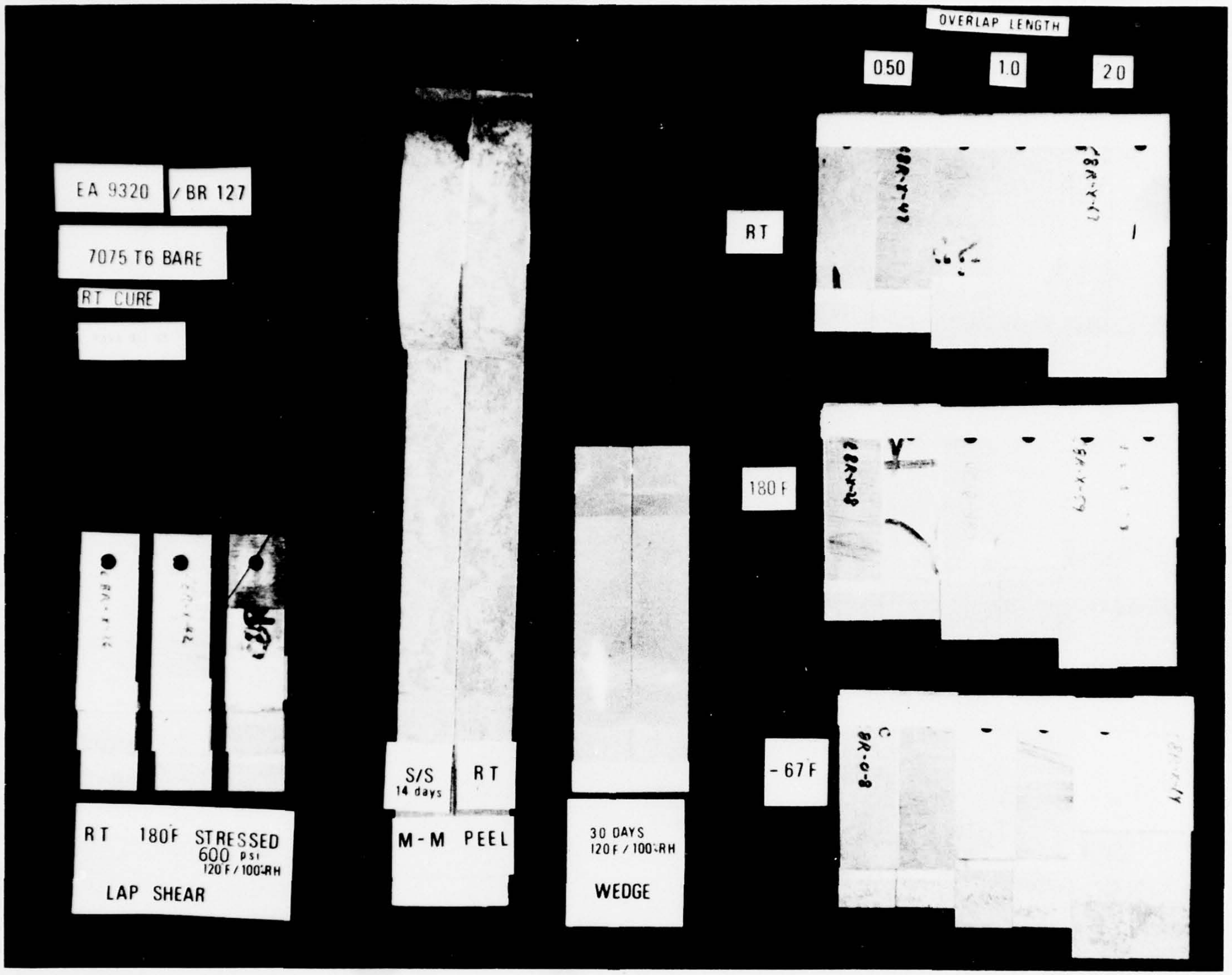


Figure 75.—Specimen Failure Surfaces—EA 9320, PasaJell 105, RT Bonds

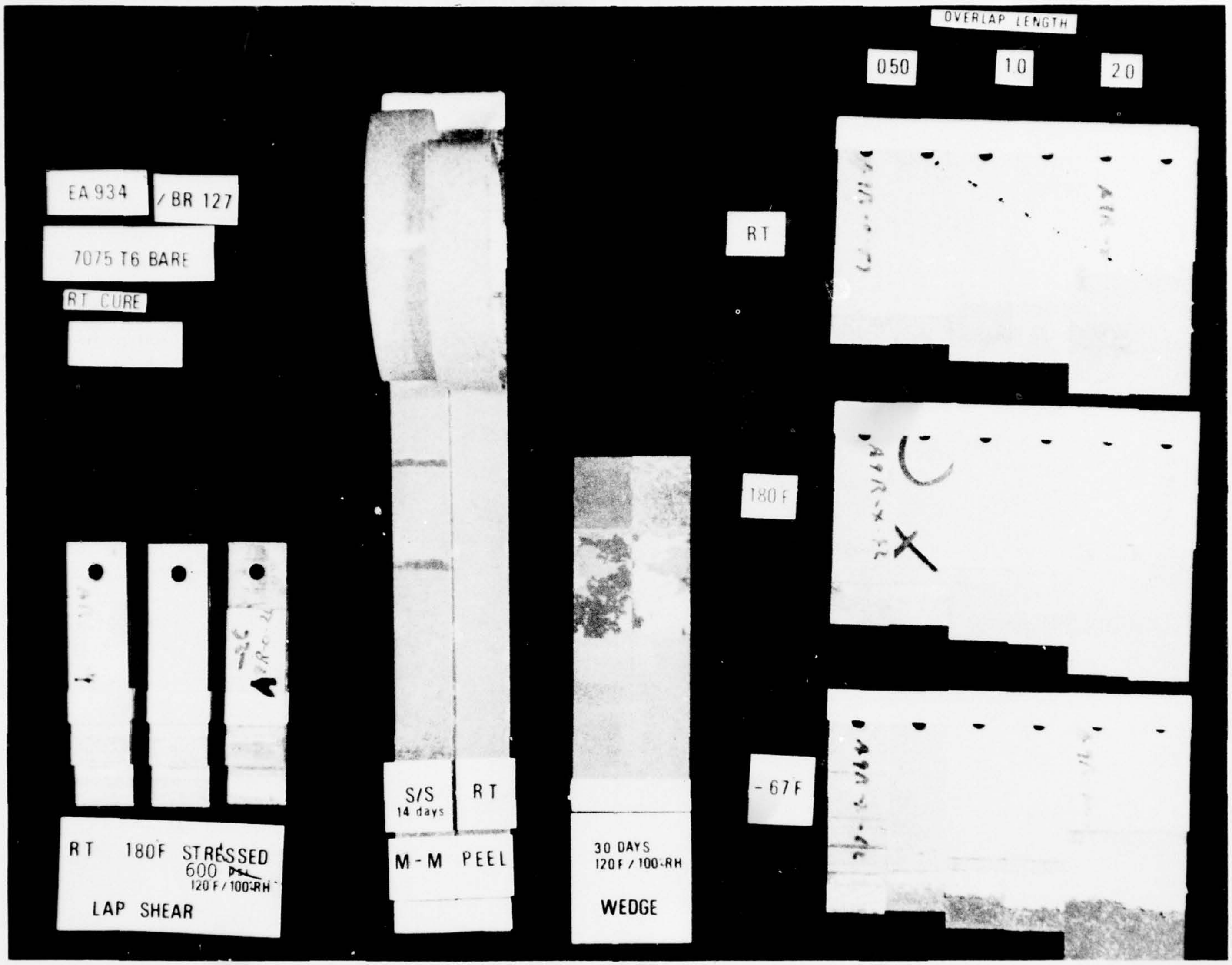


Figure 76.–Specimen Failure Surfaces–EA 934, Optimized FPL Etch, RT Bonds

AD-A061 758 BOEING COMMERCIAL AIRPLANE CO SEATTLE WASH F/G 13/8
ANODIZE OPTIMIZATION AND ADHESIVE EVALUATIONS FOR REPAIR APPLIC--ETC(U)
JUL 78 M C LOCKE, R E HORTON, J E MCCARTY F33615-73-C-5171
UNCLASSIFIED AFML-TR-78-104 NL

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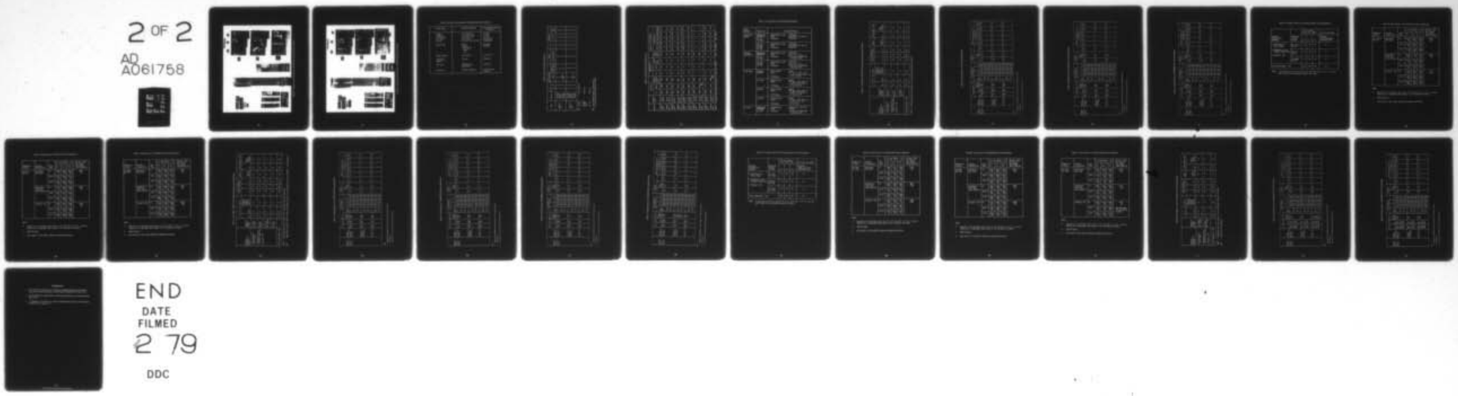

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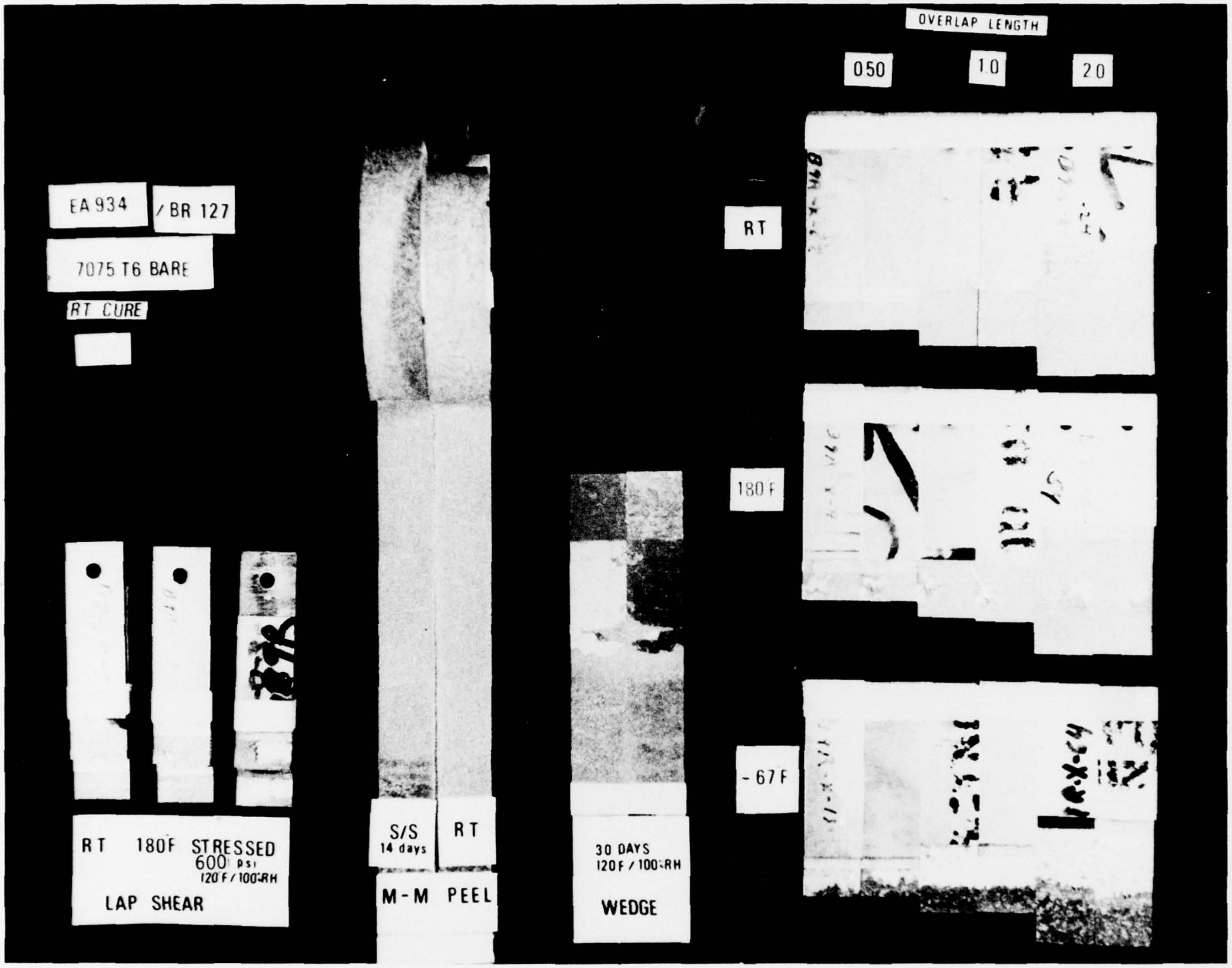

Figure 77.—Specimen Failure Surfaces—EA 934, Non-Tank Anodized, RT Bonds

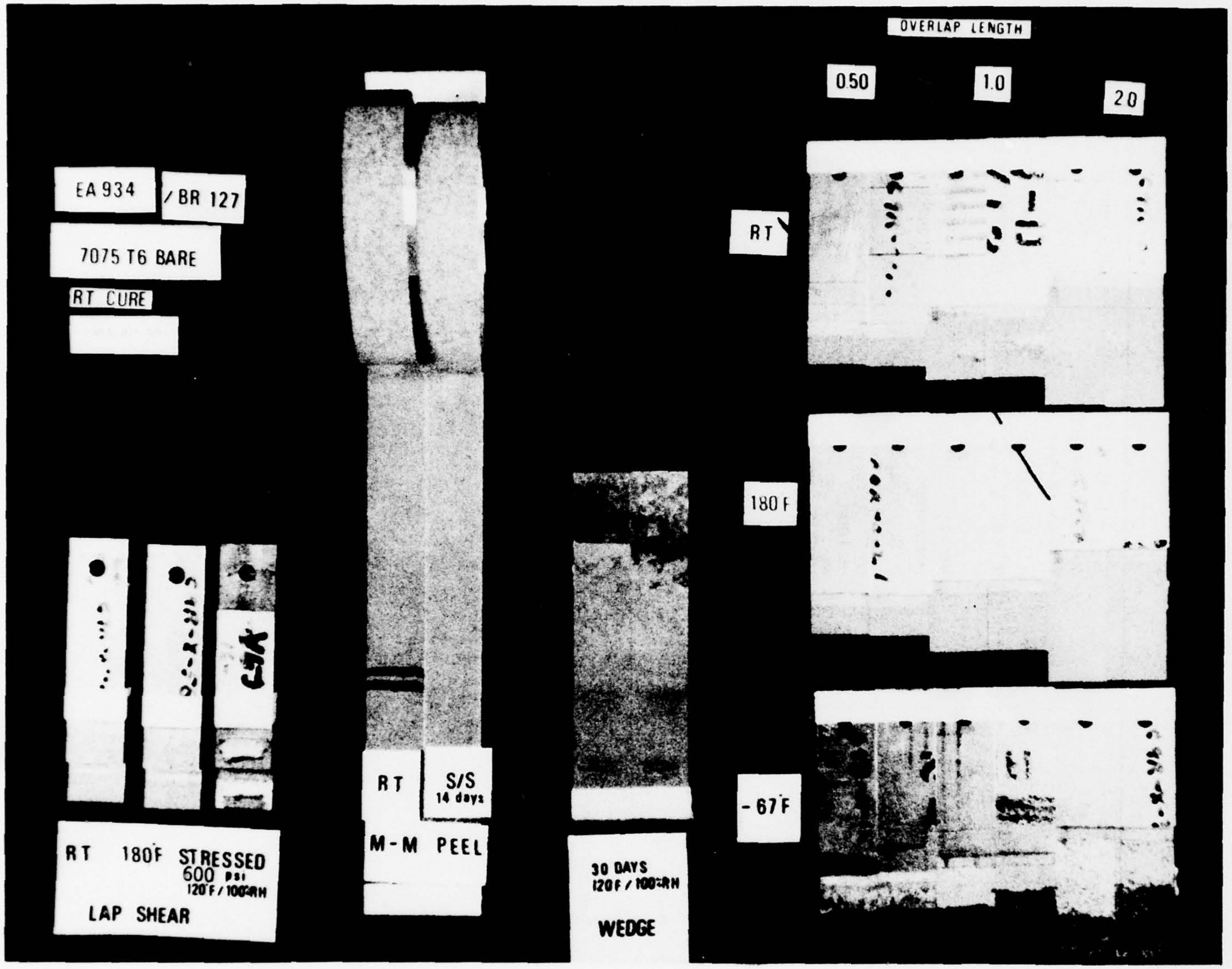

Figure 78.—Specimen Failure Surfaces—EA 934, PasaJell 105, RT Bonds

Table 1.—Summary of Variables and Processing Conditions Investigated

Process variable	Conditions investigation	Recommended processing conditions
Voltage	1, 2, 4, 6, 10 volts	4 - 6 volts
Temperature	40, RT(70-80), 100°F	70 - 80°F
Anodizing time	1, 5, 10, 15, 20 min	10 - 15 min
Rinse delay	0, 2, 5, 10 min	less than 5 min
Part size	6" x 6", 6" x 12", 24" x 24"	All satisfactory
Anodize mode	Vertical	Satisfactory
	Horizontal	Satisfactory
	Both surfaces	
	Bottom	
	Top	
Battery anodizing	2, 4, 6, 12 volts	6 and 12 volts
Anodizing over fasteners	Ti and Al	Satisfactory
Bare vs clad	7076-T6 bare and 2024-T3 clad	Satisfactory
Common error	4 conditions identified	Corrective actions provided

Table 2.—Bond Verification Test Matrix

Alloy	Adhesive [1]	0.5-inch lap shear			Wedge	M/M peel		
		RT	180°F	1200 psi stress [2]	120°F/100% RH	RT	−67°F	Salt spray
2024-T3 Clad	AF 127-3	X	X	X	X	X	X	X
	EA 9601	X	X	X	X	X	X	X
	FM 73	X	X	X	X	X	X	X
	AF 130	X	(350°F)	X	X	X	X	X
	EA 9320	X	X	X	X	X	X	X
7075-T6 Bare	AF 127-3	X	X	X	X	X	X	X
	EA 9601	X	X	X	X	X	X	X
	FM 73	X	X	X	X	X	X	X
	AF 130	X	(350°F)	X	X	X	X	X
	EA 9320	X	X	X	X	X	X	X

[1] EA 9320 — RT cure system

AF 127-3
EA 9601 — 250°F cure
FM 73

AF 130 — 350° cure

[2] 120 F/100% RH exposure, 4 specimens each
all others are 5 specimens. 600 psi for EA 9320

Table 3.—Summary Bond Verification Tests

Adherend	Adhesive primer	Lap shear, psi			Metal-metal peel lb in./in.			Wedge test -120 °F/100% RH					
								Initial length inches	Crack growth, in.				
		RT	180°F	1200 psi sustained stress	RT	−67°F	14 day salt spray		1 hr	4 hr	24 hr	14 day	30 day
2024T3 clad	FM 73-/ BR 127	4670	3560	4400	66	59	64	1.38	0.01	0.05	0.07	0.10	0.13
7075T6 bare	FM 73/ BR 127	5080	3818	4900	51	42	52	1.48	0.01	0.01	0.04	0.11	0.14
2024T3 clad	AF 127-3/ BR 127	4452	2705	3634	79	22	74	1.33	0.16	0.18	0.18	0.28	0.40
7075T6 bare	AF 127-3/ BR 127	4932	2870	3991	60	10	58	1.46	0.18	0.20	0.20	0.32	0.42
2024T3 clad	EA 9601/ BR 127	4744	3528	4810	56	8	44	1.59	0.08	0.10	0.15	0.22	0.25
7075T6 bare	EA 9601/ BR 127	5340	3664	5275	39	6	45	1.69	0.11	0.11	0.15	0.24	0.30
2024T3 clad	AF 130/ EC 2333	1668	2074	3040	4	12	8	2.52	0	0	0	0	0
7075T6 bare	AF 130/ EC 2333	1646	1817 ▷1	3244	3	10	8	2.85	0	0	0	0	0
2024T3 clad	EA 9320/ BR 127	3496	775	3545	57	7	57	1.34	0.06	0.06	0.13	0.50	0.65
7075T6 bare	EA 9320/ BR 127	3608	554	3630 ▷2	48	4	47	1.52	0.12	0.12	0.12	0.29	0.50

NOTE: Average of 5 specimens each test PANTA - 6 volts, 10 min 70-80°F ▷1 Test at 350°F ▷2 600 psi

Table 4.—Cure Conditions for Adhesive/Primer Systems

Cure Method	Materials	Cure Conditions	
Autoclave Bonds	<u>Adhesives</u> AF 127-3 FM 73 EA 9628	Temperature rise: Cure: Pressure:	4-6°F/min 225-250°F for 90 min 35-50 psi
	AF 130 FM 400 FM 300 AF 143	Temperature rise: Cure: Pressure:	4-6°F/min 340-360°F for 60 min 35-50 psi
Vacuum Bag Bonds	<u>Adhesives</u> AF 127-3 FM 73 EA 9628	Temperature rise: Cure: Pressure:	4-6°F/min 200°F for 2 hrs 10-14 psi vacuum bag pressure only
	AF 130 FM 400 AF 143	Temperature rise: Cure: Pressure:	4-6°F/min 300°F for 2 hrs 10-14 psi vacuum bag pressure only
Oven Bake	<u>Primers</u> BR 127	Application: Cure: Thickness:	Spray Air dry 1/2 hr, then cure at 250°F for 1 hr 0.1 to 0.4 mil
	EC 2333	Application: Cure: Thickness:	Spray Air dry, then bake at 160°F for 30 min 0.1 to 0.4 mil
	BR 400	Application: Cure: Thickness:	Spray Air dry, then bake at 200°F for 30 min 0.1 to 0.2 mil
	EC 3917	Application: Cure: Thickness:	Spray Air dry, then bake at 250°F for 1 hr 0.1-0.4 mil
RT Cure	<u>Adhesives</u> EA 9320 EA 934	Temperature: Cure: Pressure:	Ambient RT (70-75°F) 7 days 10-14 psi vacuum bag pressure only

Table 5.—Test Matrix, 250° F Cure Adhesive Systems—Autoclave Bonds

Surface Preparation Methods	Adhesive System/ Primer	0.5-in Lap Shear			L/t Lap Shear -67°F, RT, 180°F			Wedge	Metal-Metal Peel	
		RT	180°F	60 Days 1200 psi Stress, 120°F/ 100% RH	0.5	1.0	2.0	120°F/ 100% RH	RT	Salt Spray, 14 Days
o Optimized FPL Etch (Tank) o Phosphoric Acid Anodize (Non-Tank) o PasaJell 105	AF 127-3/ BR 127	15	15	12	45	45	45	15	15	15
	FM 73/ BR 127	15	15	12	45	45	45	15	15	15
	EA 9628/ BR 127	15	15	12	45	45	45	15	15	15
Total Specimens = 666		45	45	36	135	135	135	45	45	45

NOTE: 5 specimens each test except 4 for sustained stressed lap shear.

Table 6.—Data Summary—AF 127, Autoclave Bonds

Adhesive/ Primer	Surface Preparation	0.5-in Lap Shear, psi			L/t Lap Shear, lb -67°F, RT, 180°F				M-M Peel, lb-in./in.		Wedge Crack Extension, inch					
												120°F/100% RH				
		RT	180°F	1200 psi Stress, 60 days	Test Temp.	0.5 in.	1.0 in.	2.0 in.	RT	Salt Spray 14 days	Initial	1 hour	4 hours	24 hours	14 days	30 days
AF 127-3/ BR 127	Optimized FPL etch	4948 48	3048 135	4395 154	RT	2482 43	4322 21	8176 255	54 1.2	57.9 2.0	1.45	0.04	0.15	0.28	0.50	0.50
					180°F	1624 22	2632 48	5452 215								
					-67°F	3268 272	4020 65	6754 622								
	Phosphoric acid non-tank anodize	5064 77	3300 108	4267 234	RT	2522 37	4384 81	8012 58	53.8 3.6	54.0 1.5	1.46	0.07	0.20	0.33	0.43	0.53
					180°F	1626 27	2948 94	5578 61								
					-67°F	3456 131	4454 320	6554 737								
	PasaJell 105	5044 138	3320 135	4055 209	RT	2538 30	4350 61	7768 423	51.8 1.3	56.1 2.3	1.42	0.07	0.29	0.59	0.79	0.87
					180°F	1620 52	2824 102	5500 169								
					-67°F	3160 231	3514 138	4438 610								

NOTE:

- o Average of 5 specimens each test except 4 for stressed lap shear.
- o 7075-T6 bare.
- o Sub values in the table indicate standard deviation.

Table 7.—Data Summary—FM 73/BR 127, Autoclave Bonds

		0.5-in Lap Shear, psi			L/t Lap Shear, lb -67°F, RT, 180°F				M-M Peel, lb-in./in.		Wedge Crack Extension, inch					
												120°F/100% RH				
Adhesive/ Primer	Surface Preparation	RT	180°F	1200 psi Stress, 60 days	Test Temp.	0.5 in.	1.0 in.	2.0 in.	RT	Salt Spray 14 days	Initial	1 hour	4 hours	24 hours	14 days	30 days
FM 73/ BR 127	Optimized FPL etch	5036 57	3948 21	4615 209	RT	2538 58	4368 87	7274 327	45.0 2.1	44.7 2.9	1.49	0	0	0	0.05	0.12
					180°F	1992 36	3124 85	5654 229								
					-67°F	3422 96	4614 205	7278 339								
	Phosphoric acid non-tank anodize	4884 163	3796 33	4695 128	RT	2410 31	4306 45	7238 212	40.0 0	43.5 0	1.52	0	0	0	0.04	0.07
					180°F	1830 60	3084 50	5666 158								
					-67°F	3268 108	4494 179	7250 191								
	PasaJell 105	5000 158	3748 27	4590 189	RT	2452 53	4268 67	6970 217	45.6 1.3	45.6 0.8	1.44	0.15	1.10	2.09	2.17	2.24
					180°F	1924 49	3046 105	5602 221								
					-67°F	3280 110	4536 47	6706 165								

NOTE:

- Average of 5 specimens each test except 4 for stressed lap shear.
- 7075-T6 bare.
- Sub values in the table indicate standard deviation.

Table 8.—Data Summary—EA 9628/BR 127, Autoclave Bonds

Adhesive/ Primer	Surface Preparation	0.5-in Lap Shear, psi			L/t Lap Shear, lb -67°F, RT, 180°F				M-M Peel, lb-in./in.		Wedge Crack Extension, inch					
												120°F/100% RH				
		RT	180°F	1200 psi Stress, 60 days	Test Temp.	0.5 in.	1.0 in.	2.0 in.	RT	Salt Spray 14 days	Initial	1 hour	4 hours	24 hours	14 days	30 days
EA 9628/ BR 127	Optimized FPL etch	5516 41	4024 93	5070 279	RT	2774 27	4824 31	7828 138	58.0 1.2	55.7 1.4	1.47	0.03	0.15	0.23	0.48	0.56
					180°F	2040 37	3350 61	6094 62								
					-67°F	3682 37	4810 32	6852 290								
	Phosphoric acid non-tank anodize	5432 67	4056 70	5000 114	RT	2722 34	4692 27	7808 273	52.8 2.9	54.9 2.3	1.52	0	0.02	0.09	0.11	0.15
					180°F	1984 9	3300 10	6164 98								
					-67°F	3652 26	4676 149	7170 137								
	PasaJell 105	5252 119	3696 234	4750 285	RT	2666 36	4536 116	7188 245	55.8 2.4	55.5 2.1	1.51	0.07	0.88	1.75	2.18	2.25
					180°F	1896 31	3276 39	6284 65								
					-67°F	2906 323	3120 672	3970 422								

NOTE:

- o Average of 5 specimens each test except 4 for stressed lap shear.
- o 7075-T6 bare.
- o Sub values in the table indicate standard deviation.

Table 9.—Test Matrix, 250° F Cure Adhesive Systems—Vacuum Bag Bonds

Surface Preparation Methods	Adhesive System/ Primer	L/t Lap Shear -67°F, RT, 180°F			0.5-in Lap Shear
		0.5	1.0	2.0	60 Days, 1200 psi Stress 120°F/100% RH
o Optimized FPL Etch (Tank) o Phosphoric Acid Anodize (Non-Tank) o PasaJell 105	AF 127-3/ BR 127	75	45	45	12
	FM 73/ BR 127	75	45	45	12
	EA 9628/ BR 127	75	45	45	12
Total Specimens = 531		225	135	135	36

NOTE: 5 specimens each test except 10 for RT and 180°F 1/2-in. overlap and 4 each for sustained stressed lap shear.

Table 10.—Data Summary—AF 127-3/BR 127, Vacuum Bag Bonds

Adhesive/ Primer	Surface Preparation	Test Temp.	L/t Lap Shear - lb 0.5 in.	1.0 in.	2.0 in.	60-day, 1200 psi stress lap shear, 120°F/100% RH
AF 127-3/ BR 127	Optimized FPL etch	RT	2467 96	3960 376	7376 446	4390 252
		180°F	1558 56	2644 296	5264 176	
		-67°F	3178 42	4198 402	6896 747	
	Phosphoric acid non-tank anodize	RT	2390 244	4194 75	7372 532	4450 129
		180°F	1553 67	2770 90	4964 667	
		-67°F	3178 127	3932 341	5880 772	
	PasaJell 105	RT	2194 266	3632 331	6724 428	3745 654
		180°F	1449 201	2688 487	5604 453	
		-67°F	2360 260	2914 285	3658 318	

NOTE:

- o Average of 10 specimens each test for RT and 180°F, 1/2-in. overlap; others are 5 specimens each except 4 for stressed lap shear.
- o 7075-T6 bare.
- o Sub values in the table indicate standard deviation.

Table 11.—Data Summary—FM 73/BR 127, Vacuum Bag Bonds

Adhesive/ Primer	Surface Preparation	Test Temp.	L/t Lap Shear - lb 0.5 in.	1.0 in.	2.0 in.	60-day, 1200 psi stress lap shear, 120°F/100% RH
FM 73/ BR 127	Optimized FPL etch	RT	2400 51	3964 100	6542 282	4380 375
		180°F	1786 81	2788 97	5118 191	
		-67°F	3144 84	3908 50	5938 321	
	Phosphoric acid non-tank anodize	RT	2274 45	3658 106	6080 147	4560 347
		180°F	1681 47	2604 21	4902 33	
		-67°F	3074 42	3860 105	5658 366	
	PasaJell 105	RT	2290 113	3478 301	5602 193	4150 640
		180°F	1593 171	2576 264	5096 405	
		-67°F	2760 167	3286 213	4632 643	

NOTE:

- o Average of 10 specimens each test for RT and 180°F, 1/2-in. overlap; others are 5 specimens each except 4 for stressed lap shear.
- o 7075-T6 bare.
- o Sub values in the table indicate standard deviation.

Table 12.—Data Summary—EA 9628/BR 127, Vacuum Bag Bonds

Adhesive/ Primer	Surface Preparation	Test Temp.	L/t Lap Shear - lb 0.5 in.	1.0 in.	2.0 in.	60-day, 1200 psi stress lap shear, 120°F/100% RH
EA 9628/ BR 127	Optimized FPL etch	RT	2249 124	3616 197	5852 511	4155 240
		180°F	1526 120	2506 72	5158 72	
		-67°F	3028 164	3670 219	5260 62	
	Phosphoric acid non-tank anodize	RT	2144 169	3960 115	6374 420	4300 82
		180°F	1508 93	2594 210	5120 210	
		-67°F	2968 168	4130 345	6028 107	
	PasaJell 105	RT	2133 175	3640 197	5652 389	4045 306
		180°F	1491 121	2702 181	5076 373	
		-67°F	2634 92	2872 254	3422 327	

NOTE:

- Average of 10 specimens each test for RT and 180°F, 1/2-in. overlap; others are 5 specimens each except 4 for stressed lap shear.
- 7075-T6 bare.
- Sub values in the table indicate standard deviation.

Table 13.—Test Matrix, 350° F Cure Adhesive Systems—Autoclave Bonds

Surface Preparation Methods	Adhesive System/ Primer	0.5-in. Lap Shear			L/t Lap Shear -67°F, RT, 350°F			Wedge	Metal-Metal Peel	
		RT	350°F	60 Days 1200 psi Stress, 120°F/ 100% RH	0.5	1.0	2.0	120°F/ 100% RH	RT	Salt Spray, 14 Days
o Optimized FPL Etch (Tank) o Phosphoric Acid Anodize (Non-Tank) o PasaJell 105	AF 130/ EC 2333	15	15	12	45	45	45	15	15	15
	FM 400/ BR 400	15	15	12	45	45	45	15	15	15
	FM 300/ BR 127 (1)	15	15	12	45	45	45	15	15	15
	AF 143/ EC 3917	15	15	12	45	45	45	15	15	15
Total Specimens = 888		60	60	48	180	180	180	60	60	60

NOTE: 5 specimens each test except 4 for sustained stressed lap shear.

(1) Additional tests at 300°F, 250°F with/without primer on optimized FPL etch and PANTA -- 40 specimens.

Table 14.—Data Summary—AF 130/EC 2333, Autoclave Bonds

Adhesive/ Primer	Surface Preparation	0.5-in Lap Shear, psi			L/t Lap Shear, lb -67°F, RT, 180°F				M-M Peel, lb-in./in.		Wedge Crack Extension, inch					
												120°F/100% RH				
		RT	350°F	1200 psi Stress, 60 days	Test Temp.	0.5 in.	1.0 in.	2.0 in.	RT	Salt Spray 14 days	Initial	1 hour	4 hours	24 hours	14 days	30 days
AF 130/ EC 2333	Optimized FPL etch	2680 190	2400 91	4025 229	RT	1340 57	1277 75	1478 94	3.0 0	3.0 0	2.56	0.03	0.03	0.03	0.03	0.03
					350°F	1166 25	1622 133	2204 31								
					-67°F	1186 87	1254 73	1390 101								
	Phosphoric acid non-tank anodize	2475 145	2504 38	3880 285	RT	1240 76	1406 94	1550 107	3.3 0.3	3.1 0.2	2.76	0	0	0	0	0.04
					350°F	1227 17	1688 95	2328 94								
					-67°F	1132 121	1400 93	1292 89								
	PasaJell 105	2656 257	2352 50	3885 193	RT	1250 87	1260 74	1354 138	3.0 0	4.8 0.7	2.39	0.01	0.01	0.01	0.02	0.06
					350°F	1150 55	1478 41	2012 90								
					-67°F	1112 11	1138 84	1306 119								

NOTE:

- Average of 5 specimens each test except 4 for stressed lap shear.
- 7075-T6 bare.
- Sub values in the table indicate standard deviation.

Table 15.—Data Summary—FM 400/BR 400, Autoclave Bonds

Adhesive/ Primer	Surface Preparation	0.5-in Lap Shear, psi			L/t Lap Shear, lb -67°F, RT, 180°F				M-M Peel, lb-in./in.		Wedge Crack Extension, inch					
												120°F/100% RH				
		RT	350°F	1200 psi Stress, 60 days	Test Temp.	0.5 in.	1.0 in.	2.0 in.	RT	Salt Spray 14 days	Initial	1 hour	4 hours	24 hours	14 days	30 days
FM 400/ BR 400	Optimized FPL etch	3770 337	3210 152	3900 134	RT	1876 304	1876 172	2080 227	3.0 0	3.0 0	1.72	0.04	0.07	0.07	0.12	0.14
					350°F	1655 60	1970 145	2588 271								
					-67°F	1803 263	2080 262	2052 223								
	Phosphoric acid non-tank anodize	3948 367	2920 228	3480 198	RT	1962 256	1808 198	2062 432	3.0 0	3.5 0	1.79	0.10	0.13	0.15	0.21	0.23
					350°F	1468	1749 187	2526 192								
					-67°F	1745 276	1928 197	2033 197								
	PasaJell 105	3364 305	2892 137	3480 210	RT	1794 124	1798 202	1918 212	3.0 0	3.0 0	1.75	0	0.05	0.09	0.12	0.13
					350°F	1477 58	1766 134	2474 292								
					-67°F	1784 237	1770 270	1822 189								

NOTE:

- o Average of 5 specimens each test except 4 for stressed lap shear.
- o 7075-T6 bare.
- o Sub values in the table indicate standard deviation.

Table 16,–Data Summary–FM 300/BR 127, Autoclave Bonds

Adhesive/ Primer	Surface Preparation	0.5-in Lap Shear, psi			L/t Lap Shear, lb -67°F, RT, 180°F				M-M Peel, lb-in./in.		Wedge Crack Extension, inch					
												120°F/100% RH				
		RT	350°F	1200 psi Stress, 60 days	Test Temp.	0.5 in.	1.0 in.	2.0 in.	RT	Salt Spray 14 days	Initial	1 hour	4 hours	24 hours	14 days	30 days
FM 300/ BR 127	Optimized FPL etch	5460 153	840 285	5300 277	RT	2740 63	3840 28	6066 227	18.8 1.3	18.3 0.7	1.68	0	0	0	0	0.01
					350°F	423 60	763 41	1218 60								
					-67°F	1854 93	2026 78	2612 163								
	Phosphoric acid non-tank anodize	4944 135	832 107	5270 96	RT	2496 43	3958 108	6062 106	14.4 1.7	14.1 2.1	1.66	0	0	0.01	0.01	0.01
					350°F	397 69	748 36	1307 106								
					-67°F	1930 407	2016 156	2336 201								
	PasaJell 105	5436 121	676 110	5070 234	RT	2634 70	3678 304	5514 645	19.2 4.5	15.8 3.1	1.77	0.17	0.29	0.29	0.46	0.46
					350°F	372 29	575 51	1120 65								
					-67°F	1646 65	1820 258	1914 174								

NOTE:

- o Average of 5 specimens each test except 4 for stressed lap shear.
- o 7075-T6 bare.
- o Sub values in the table indicate standard deviation.

Table 17.—Data Summary—AF 143/EC 3917, Autoclave Bonds

Adhesive/ Primer	Surface Preparation	0.5-in Lap Shear, psi			L/t Lap Shear, lb -67°F, RT, 180°F				M-M Peel, lb-in./in.		Wedge Crack Extension, inch					
												120°F/100% RH				
		RT	350°F	1200 psi Stress, 60 days	Test Temp.	0.5 in.	1.0 in.	2.0 in.	RT	Salt Spray 14 days	Initial	1 hour	4 hours	24 hours	14 days	30 days
AF 143/ EC 3917	Optimized FPL etch	3970 201	2050 104	4630 151	RT	2000 104	2234 152	2968 116	7.2 0.7	7.8 0.7	1.71	0.03	0.03	0.03	0.03	0.03
					350°F	1052 34	1888 13	3434 84								
					-67°F	1478 64	1566 75	1834 97								
	Phosphoric acid non-tank anodize	4116 152	2194 162	4300 40 one spec. failed 55 days	RT	2076 88	2532 84	3350 125	6.7 0.4	7.5 0.4	1.68	0.01	0.01	0.02	0.03	0.09
					350°F	1060 31	1804 65	3254 138								
					-67°F	1344 74	1632 124	1826 232								
	PasaJell 105	3836 143	2088 134	4590 160	RT	1922 118	1932 70	2544 284	6.0 0	6.6 0.8	1.73	0	0	0	0	0.02
					350°F	1128 31	1796 26	3354 110								
					-67°F	1350 61	1434 137	1594 63								

NOTE:

- o Average of 5 specimens each test except 4 for stressed lap shear.
- o 7075-T6 bare.
- o Sub values in the table indicate standard deviation.

Table 18.—Test Matrix, 350° F Cure Adhesive Systems—Vacuum Bag Bonds

Surface Preparation Methods	Adhesive System/ Primer	L/t Lap Shear -67°F, RT, 350°F			0.5-inch Lap Shear
		0.5	1.0	2.0	60 Days, 1200 psi Stress 120°F/100% RH
o Optimized FPL Etch (Tank) o Phosphoric Acid Anodize (Non-Tank) o PasaJell 105	AF 130/ EC 2333	75	45	45	12
	FM 400/ BR 400	75	45	45	12
	AF 143/ EC 3917	75	45	45	12
Total Specimens = 531		225	135	135	36

NOTE: 5 specimens each test except 10 for RT and 350°F, 1/2-in. overlap and 4 each for sustained stressed lap shear.

Table 19.—Data Summary—AF 130/EC 2333, Vacuum Bag Bonds

Adhesive/ Primer	Surface Preparation	Test Temp.	L/t Lap Shear - lb 0.5 in.	1.0 in.	2.0 in.	60-day, 1200 psi stress lap shear, 120°F/100% RH
AF 130/ EC 2333	Optimized FPL etch	RT	1303 87	1211 89	1388 154	3535 192
		350°F	1083 45	1447 42	2064 50	
		-67°F	1252 187	1057 91	1188 129	
	Phosphoric acid non-tank anodize	RT	1285 147	1266 107	1486 120	3685 194
		350°F	1104 57	1492 55	2225 85	
		-67°F	1194 145	1236 112	1548 281	
	PasaJell 105	RT	1333 178	1201 119	1471 171	3695 266
		350°F	1078 73	1308 233	1951 159	
		-67°F	1107 72	1280 181	1165 111	

NOTE:

- o Average of 10 specimens each test for RT and 350°F, 1/2-in. overlap; others are 5 specimens each except 4 for stressed lap shear.
- o 7075-T6 bare.
- o Sub values in the table indicate standard deviation.

Table 20.—Data Summary—FM 400/BR 400, Vacuum Bag Bonds

Adhesive/ Primer	Surface Preparation	Test Temp.	L/t Lap Shear - lb 0.5 in.	1.0 in.	2.0 in.	60-day, 1200 psi stress lap shear, 120°F/100% RH
FM 400/ BR 400	Optimized FPL etch	RT	1786 254	1801 250	1927 196	3205 637
		350°F	1304 177	1686 185	2422 236	
		-67°F	1608 263	1700 213	1906 317	
	Phosphoric acid non-tank anodize	RT	1825 238	1782 194	2010 356	3765 351
		350°F	1321 105	1573 227	2242 358	
		-67°F	1802 215	1786 166	2218 164	
	PasaJell 105	RT	1539 251	1858 34	1960 239	2800 327
		350°F	1255 155	1606 201	2179 434	
		-67°F	1440 308	1751 221	1607 142	

NOTE:

- o Average of 10 specimens each test for RT and 350°F, 1/2-in. overlap; others are 5 specimens each except 4 for stressed lap shear.
- o 7075-T6 bare.
- o Sub values in the table indicate standard deviation.

Table 21.—Data Summary—AF 143/EC 3917, Vacuum Bag Bonds

Adhesive/ Primer	Surface Preparation	Test Temp.	L/t Lap Shear - lb 0.5 in.	1.0 in.	2.0 in.	60-day, 1200 psi stress lap shear, 120°F/100% RH
AF 143/ EC 3917	Optimized FPL etch	RT	2053 62	2472 58	3308 78	4615 357
		350°F	954 74	1632 69	2890 187	
		-67°F	1572 155	1752 95	1862 176	
	Phosphoric acid non-tank anodize	RT	1985 59	2264 59	3046 118	4710 244
		350°F	887 127	1476 152	2810 221	
		-67°F	1568 85	1682 98	1890 64	
	PasaJell 105	RT	1860 142	2187 96	3010 110	4726 31
		350°F	933 125	1734 50	2950 475	One specimen failed during loading
		-67°F	1355 139	1406 115	1776 236	

NOTE:

- o Average of 10 specimens each test for RT and 350°F, 1/2-in. overlap; others are 5 specimens each except 4 for stressed lap shear.
- o 7075-T6 bare.
- o Sub values in the table indicate standard deviation.

Table 22.—Test Matrix, Room Temperature Cure Adhesive Systems

Surface Preparation Methods	Adhesive System/ Primer	0.5-in. Lap Shear			L/t Lap Shear -67°F, RT, 180°F			Wedge	Metal-Metal Peel	
		RT	180°F	60 Days 1200 psi Stress, 120°F/ 100% RH	0.5	1.0	2.0	120°F/ 100% RH	RT	Salt Spray, 14 Days
o Optimized FPL Etch (Tank)	EA 9320/ BR 127 (1)	15	15	12	45	45	45	15	15	15
o Phosphoric Acid Anodize (Non-Tank) o PasaJell 105	EA 934/ BR 127 (1)	15	15	12	45	45	45	15	15	15
Total Specimens = 444		30	30	24	90	90	90	30	30	30

NOTE: 5 specimens each test except 4 for sustained stressed lap shear.

(1) Retest of 90 specimens.

Table 23.—Data Summary—EA 9320/BR 127, RT Cure Bonds

		0.5-in Lap Shear, psi			L/t Lap Shear, lb -67°F, RT, 180°F				M-M Peel, lb-in./in.		Wedge Crack Extension, inch					
												120°F/100% RH				
Adhesive/ Primer	Surface Preparation	RT	180°F	600 psi Stress, 60 days	Test Temp.	0.5 in.	1.0 in.	2.0 in.	RT	Salt Spray 14 days	Initial	1 hour	4 hours	24 hours	14 days	30 days
EA 9320/ BR 127	Optimized FPL etch	1584 244	250 82	3767 110	RT	886 263	2068 260	3060 402	48.2 10.7	54.9 5.5	1.59	0.44	0.69	0.92	1.17	1.29
		3660 563 retest	593 80 retest		180°F	119 29	206 40	383 85								
					-67°F	2162 462	2320 616	3972 767								
	Phosphoric acid non-tank anodize	2636 311	380 39	3680 257	RT	1302 223	2458 217	4864 414	48.6 3.3	47.7 1.6	1.44	0.70	0.91	1.11	1.30	1.37
		3793 141 retest	693 50 retest		180°F	176 33	321 18	590 21								
					-67°F	2558 209	3308 317	4534 387								
	PasaJell 105	2316 748	349 146	2353 50 one spec. failed 28 days	RT	1506 450	2430 600	4764 797	40.5 2.4	40.2 3.1	1.45	0.30	0.53	0.76	1.00	1.12
		3410 551 retest	486 46 retest		180°F	214 46	379 44	687 153								
					-67°F	2422 460	2656 394	3354 331								

NOTE:

- Average of 5 specimens each test except 4 for stressed lap shear.
- 7075-T6 bare.
- Sub values in the table indicate standard deviation.

Table 24.—Data Summary—EA 934/BR 127, RT Cure Bonds

Adhesive/ Primer	Surface Preparation	0.5-in Lap Shear, psi RT	0.5-in Lap Shear, psi 180°F	0.5-in Lap Shear, psi 600 psi Stress, 60 days	L/t Lap Shear, lb -67°F, RT, 180°F Test Temp.	L/t Lap Shear 0.5 in.	L/t Lap Shear 1.0 in.	L/t Lap Shear 2.0 in.	M-M Peel, lb-in./in. RT	M-M Peel Salt Spray 14 days	Wedge Crack Extension, inch Initial	120°F/100% RH 1 hour	4 hours	24 hours	14 days	30 days
EA 934/ BR 127	Optimized FPL etch	2284 267	1436 60	4090 137	RT	1232 66	1948 154	2928 173	10.5 2.4	13.8 0.1	2.64	0.08	0.16	0.19	0.23	0.35
		3080 482 retest	1882 423 retest		180°F	424 86	882 97	1281 163								
					-67°F	1646 96	1678 85	1950 241								
	Phosphoric acid non-tank anodize	2860 414	878 123	4125 57	RT	1118 141	1846 465	2850 370	15.0 1.5	15.6 1.7	2.21	0.10	0.15	0.23	0.44	0.53
		3272 375 retest	893 197 retest		180°F	436 84	702 103	1289 132								
					-67°F	1324 270	1436 161	1990 342								
	PasaJell 105	2840 234	1292 108	3810 674	RT	1302 234	2124 197	3230 77	7.8 3.2	14.7 1.3	2.13	0.13	0.15	0.18	0.43	0.57
		2440 105 retest	813 266 retest		180°F	657 46	993 81	1519 264								
					-67°F	1829 156	1808 58	2096 193								

NOTE:

- o Average of 5 specimens each test except 4 for stressed lap shear.
- o 7075-T6 bare.
- o Sub values in the table indicate standard deviation.

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